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Background Paper 13

Developments in Building Products: Opportunities for Industrial Minerals

By:
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Courtesy of Ontario Hydro Placement of magnesium phosphate-based cement concrete at low temperatures.

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Executive Summary

SCOPE AND APPROACH

This study assesses opportunities for Ontario's industrial minerals producers to increase the use of their minerals in building products. The scope of the study has been limited to consideration of the building sector of the construction industry and the products/materials used by that sector, and does not address civil engineering works. The approach taken has been to identify trends and new directions in construction practice and materials technology that are currently in use or at advanced levels of development, and that could substantially encourage increased use of industrial minerals. To validate this approach, the issues have been discussed with representatives of industry and government familiar with both construction and building materials. Other information has been obtained from published sources and visits to building technology centres in Britain and Japan.

DEFINITIONS AND SIZE

The building sector of the construction industry is responsible for the production, repair and renovation of residential, industrial, commercial, institutional and public structures. In 1987, Canadian building construction was valued at ~$48.7-billion, providing 71% of the total value of construction activity. Of this, ~$25-billion (44.5%) was contributed by building in Ontario. The production and processing of industrial minerals constitutes a part of mining activity in Canada. In 1987, the Canadian industry shipped ~$5.7-billion in value of industrial minerals, of which ~$1.6-billion was produced in Ontario. The manufacturing of building products involves processing primary minerals into products and secondary materials used by the construction industry. In Ontario, the output of the building products industry is ~$6–7-billion annually, a major part of which results from the recovery and processing of industrial minerals into cement, bricks and glass.

Industrial minerals producers can increase the value of their shipments as follows:

- by continuing to supply products to a growing construction market;
- by encouraging the development of new building materials and practices that use industrial mineral products;
- by substituting Ontario-made products for imported items;
- by increasing the level of value added to their products;
- by defending against inroads by competing materials such as metals, plastics and polymers.

NEW TECHNICAL DEVELOPMENTS

The study has also examined new technical developments in building materials and practices as they affect opportunities for mineral producers. This information is presented both in terms of either mineral product types (e.g. stone, lime, gypsum, and clay), and in relation to manufactured materials commonly classed with industrial minerals (e.g. hydraulic cements, concrete products, glass and mineral fillers). New materials

that are at advanced stages of development, but have not yet been extensively used in construction are considered separately as offering long-term potential if research and development activity is initiated. Other materials, such as plastics, are discussed in regard to the competition that they present to industrial minerals.

Among the mineral-based products, the cement and concrete product groups are seen to be advancing the most rapidly. Over the past 20 years, there has been a marked transformation in cement and concrete technology. This has largely resulted from extensive efforts to develop new cements, aggregates and admixtures, and from research into the materials science of cemented products. The fruits of these efforts are now being seen in advanced concrete materials and major improvements in the productivity of concrete placement. In this area, Canadian technology is at a world-class level of development.

Other areas also have seen major development, in particular in the use of glass. However, though important to the construction industry, these mostly affect the quality and performance of the end product, and have little direct impact on the use of industrial minerals.

Some industrial minerals are being used in high-technology building products. Concretes of exceptionally high-strength and cement-based composites are both competitive with steel and ceramic materials in some applications. Gypsum products are also being made in composite form to compete with wood in structural and decorative applications. Mineral fillers and reinforcers are well established in the composite field and chemical modification of minerals is a fast-growing area of research that will enable new building products to be developed in the near future.

POTENTIAL THREATS — TECHNICAL AND MARKETING

While technical developments and market factors provide opportunities, at the same time they also potentially threaten the competitive position of industrial minerals. Technically, R&D efforts by the chemicals industry have produced numerous polymers and related materials that are being used along with wood, fibres, glass and metals to produce advanced building products. Similarly, research into alloys, finishes, and fabrication has produced advances in the use of metals in buildings. Many of these developments are available to meet changing demands in construction, thereby threatening both existing and new markets for industrial minerals. In many cases, these threats can be overcome if the minerals industry conducts the development work needed to produce competing products.

Other market threats are seen in the predicted decline in demand for new single-family housing. To some extent, these may be offset by the predicted growth in institutional and industrial construction and in the repair and renovation activity, discussed above. Certain types of products are specifically threatened by developments in the building industry. For example, masonry materials require installation by skilled trades people, but industry statistics show that practitioners of these trades are an aging group, with few new people being trained. It must be predicted that installation of masonry could become an increasingly expensive process unless more new people enter the trade. The alternative is loss of market share to more cost-effective, competing products such as concrete.

BARRIERS TO DEVELOPMENT AND ACCEPTANCE OF NEW PRODUCTS

Barriers exist to both the development of new products and their acceptance by the construction industry. Inadequate levels of research and development are contributing to the slow development of new materials that could improve productivity in construction. Even when new materials are available, they are not always readily accepted. While the larger construction companies and building materials producers are generally aware of the major developments in new materials and technology occurring abroad, effective technology transfer to the smaller, independent companies is less efficient. In some cases, the technology is being adopted; in others it may be seen as inappropriate; and in still other instances it may be considered too advanced. A number of factors appear to hinder the introduction of new technology into the construction process:

- concerns over liability lead the construction industry to be extremely conservative in specifying new materials or innovative practices;
- market tradition and a conservative view of structural design;
- the almost insignificant level of R&D conducted by the construction industry has meant that most of the industry has no investment in, or understanding of, the product of research effort;
- union regulations, trade demarcations, and codes may restrict the use of innovative practices, new materials, or increases in productivity and negate any advantages that they bring;
- other barriers result from fragmentation of the industry, a relatively low level of technical education among some practitioners, especially in the housing construction field, and lack of perceived short-term returns for some developments.

OPPORTUNITIES

Three major trends in the construction industry are emerging that offer potential market opportunities to the producers of industrial minerals:

- Industrialization of construction to improve productivity;
- A growing demand for repair and renovation of existing structures;
- A need to meet growing demands by purchasers of buildings concerning issues such as health and safety, durability and life-cycle costs.

Among the different groups of building products the following specific recommendations are made.

Stone

To accommodate the need for thin stone facings for panel and flooring, it is recommended that companies currently shipping unfinished stone for these purposes consider investment in available technology for cutting and polishing that would allow them to add substantial value to their product.

Lime and Silica

It is recommended that lime producers investigate the feasibility of introducing technology from abroad for the manufacture of lime-silica masonry, precast autoclaved lightweight concrete (PALC), and xonotlite composites.

Gypsum

We recommend that the gypsum producers investigate the use of gypsum in composite materials, both as a binder and as filler fibres.

It is recommended that technical and economic consideration be given to exploiting the gypsum deposits of the Moose River Region in terms of local production of materials based on gypsum-wood composites and cast gypsum masonry products.

Cement and Concrete

The general field of non-Portland cements is seen as offering a number of opportunities for the industrial minerals producers. In concrete and concrete products, the following areas are recommended as having potential for industrial minerals:

- increased utilization of marginal (alkali-reactive) aggregates by virtue of incorporation of supplementary cementing materials, polymer (resin) binders and, possibly, non-Portland cements;
- the production of low absorptivity lightweight aggregates, possibly clay or shale-based, for low-density ready-mix and precast concrete;
- high specification and coloured sands for polymer concretes;
- high strength aggregates for high, and ultra-high, strength (>100 MPa) structural concrete (e.g. traprock, corundum, manufactured, etc.);
- colourful stones for exposed aggregate finishes on panels and flooring.

Clay Products

It is recommended that the clay products industry consider recent developments in construction using panelized masonry as a direction consistent with the industrialization of building.

Because most of the finished products, and all of the clays, in the fine-clay category are imported, it is recommended that known kaolin deposits in the province be considered for their potential to supply these industries.

Mineral Fillers

It is recommended that current producers of mineral fillers evaluate the potential offered by chemical modification as a route to adding value to their products.

Asbestos Substitutes

The principal recommendation in this area is for the industrial minerals industry generally to put major effort into development of substitutes for asbestos. This area offers significant potential for markets both in the province and as exports.

New Materials

A number of new materials have been identified in the report that are not yet established in the building products field. These all offer major potential to consume industrial minerals, but all require research and development efforts.

GENERAL RECOMMENDATIONS

The following general recommendations are made jointly to the industrial minerals and building materials industry groups, and other interested bodies:

- That all sectors of the industrial minerals industry follow the strategy of adding value to their products.

POTENTIAL NEW INDUSTRIAL MINERAL-BASED PRODUCTS — RESEARCH AND DEVELOPMENT NEEDS.

Product Type	Minerals Used
Synthetic or substitute Si-fume	Silica
Synthetic wollastonite	Calcite, silica
MDF cements	Cements, gypsum, fillers
Silicate polymers	Vermiculite, other phyllosilicates
Geopolymers	Clays
PALC, xonotlite composites	Calcite, silica

- That both the industrial minerals and building materials sectors combine their efforts to introduce or develop technically effective and cost-efficient materials and processes to support the growth of factory-based construction materials.
- That a medium to long-term target for these products could include a major effort to introduce factory-made, affordable housing.
- That an agency be established to improve technology transfer to, and between, the industrial minerals, construction and building products industries.

Part I Industry Background

1. Introduction

SCOPE OF THE STUDY

The construction industry in Canada is a complex of interactions between three major industrial sectors: the building industry, the building materials manufacturing industry, and the industrial minerals producers who supply many of the raw materials to make the building products. Changes in the construction industry and technological advances in building products and construction methods could have a potential impact on the Ontario producers of industrial minerals. This report has been prepared for the Ontario Ministry of Northern Development and Mines, to help assess new market opportunities for the industrial minerals industry in the building products field.

Conventionally, construction is divided into two types of activity, differentiated largely by the structures being built:

- *Building construction* — residential, industrial, commercial, institutional and other categories of construction; and
- *Engineering construction* — construction of major civil works and infrastructure.

Building construction as a market for industrial minerals is the principal focus of this study. Accordingly, such major civil activities as highway, marine, and dam construction are not considered, in that engineering construction tends to be dominated by the use of low-value materials and established technology and is thus of less interest. In general, this report deals with building materials that have been produced by some level of processing or manufacturing from industrial minerals, rather than the bulk materials such as soil, gravel, and sand that form major components of many engineering works.

A diversity of products derived from industrial minerals (ranging from Portland cement to calcium carbonate fillers) is used in construction. Indeed, the industrial minerals producers are presently major suppliers to the construction and building products manufacturing industries. Four areas of potential influence on this supply have been identified, each of which is likely to be affected by changes in building methods and materials technology:

- Use of industrial minerals — through increased consumption of building materials in total, and through substitution of Ontario-produced minerals for those imported from outside of the province;
- Value added to industrial minerals used in building products, especially those in mineral products exported;
- Consumption of minerals locally by newly established industries in less-developed regions of the province.
- The threat of competition from other building products, most notably metal, wood and polymer-based materials.

Part I of the report provides the necessary background to the three key industries — industrial minerals, construction and building products — which are the basis for the study. This includes definitions and an outline of the relationships between industrial minerals and building products (Chapter 1);

a brief overview of the current status of the industrial minerals industry in Ontario (Chapter 2); a similar overall view of construction in the province, together with consideration of the ways in which change and innovation are accepted in the construction industry (Chapter 3); identification of three major trends that are expected to influence the future materials needs of the construction industry (Chapter 4); and an overview of the structure of the province's building products industry (Chapter 5).

Part II of the report (Chapters 6–15) examines the status and opportunities for industrial minerals within key segments of the building materials industry, namely:

- **Stone and mineral aggregates**
- **Lime products**
- **Gypsum products**
- **Hydraulic cements**
- **Concrete and cement-based products**
- **Clay building products**
- **Glass building products**
- **Polymer-based building products and filler minerals**
- **Alternatives to asbestos**

In Part II, as well, developments in new materials are identified, and their potential impact in various building material areas assessed. Finally, in Part III, opportunities for, and competitive threats to, the industrial minerals industry are analyzed, together with a presentation of the overall conclusions arising from the study.

THE RELATIONSHIP BETWEEN INDUSTRIAL MINERALS AND BUILDING MATERIALS

To understand the traditionally close relationship that has existed between the industrial mineral and building products industries, it is helpful to consider the ways in which a number of building types are constructed. The materials used for building differ somewhat depending upon the type of structure being built, and, to a lesser extent, on its location. Materials are selected not only on the basis of their utility, but also according to geographical availability and the traditions of an area — for example, while timber-clad frame houses are the norm in Atlantic Canada, in Southern Ontario, brick is the preferred exterior cladding material. The building products industry provides for these differences in taste and for the desire of individuals to see variety in the construction environment through products that can be substituted one for another to perform similar functions (Fig. 1-1).

The typical single-family house currently being produced in Ontario has two storeys, four bedrooms, two-and-a-half bathrooms and over 186 m^2 of living space [1]. Such a house

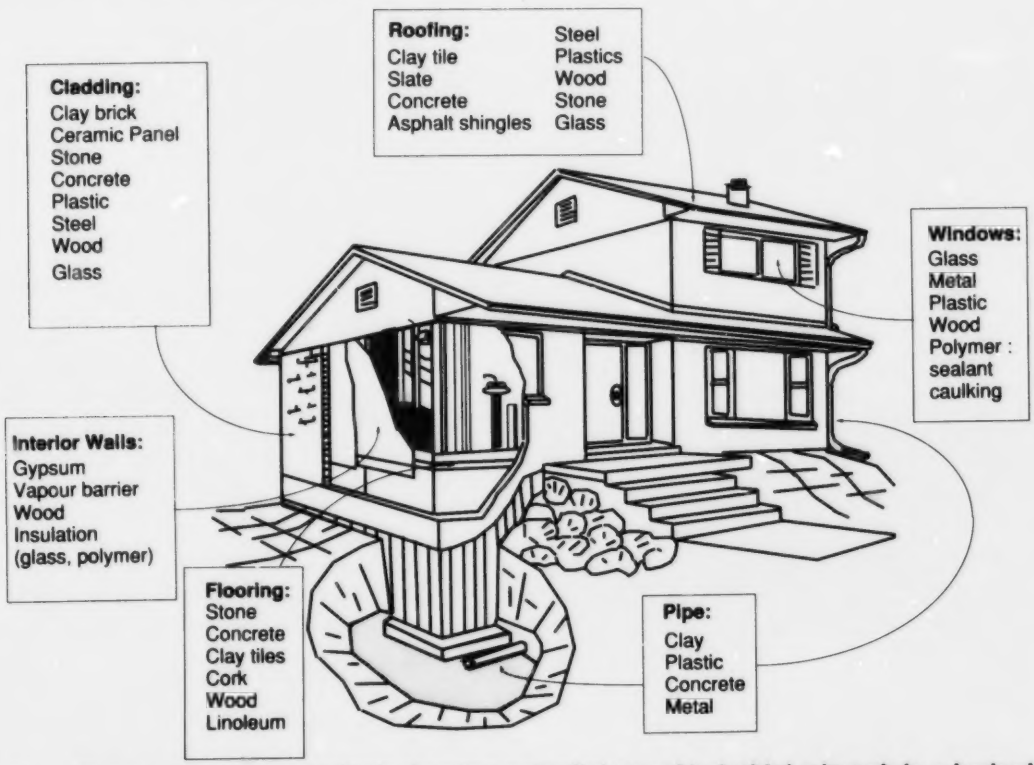

Figure 1-1 **Range of building products showing potential use of industrial minerals in a typical low-rise, single-family dwelling.**

is constructed by the so-called "stick-built" method. A concrete basement is poured in an excavated foundation, and a wood frame is erected above it. The frame supports a variety of sheathing and cladding materials that form the interior and exterior building envelopes. The outer envelope is usually fabricated in layer form, being built up from plywood or particle board, insulation, a vapour barrier and an exterior rainscreen/decorative cladding. Roofs are built from plywood, insulation and an exterior waterproof cladding, most frequently asphalt-based shingle. On the interior, the inner walls are covered with gypsum wallboard that is then painted and may be subsequently decorated with panelling or wallpaper or fabric. Windows are made from glass — although plastic materials are available — mounted in frames of wood, aluminum, vinyl-clad wood and ridged vinyl extrusions. Water services are usually made from copper pipe, while drain, waste and vent piping is almost universally plastic. Other plastic items are widely used for trim, decoration and interior fittings. Air-tightness and waterproofing of joints is attained though various forms of sealant and caulking. With the exception of pre-fabricated trusses and factory-made windows and doors, almost all of the construction process is conducted on the job-site.

It is evident that the typical low-rise house is constructed from a range of materials, some of which contain substantial quantities of industrial mineral products:

- concrete (either as block or cast-in-place) for foundations
- stone fragments on asphalt-based shingles for roofing
- clay brick for exterior cladding
- gypsum wallboard for interior cladding
- glass or mineral wool fibre for insulation
- glass for windows
- fillers, extenders and reinforcements for polymer-based products such as caulking, sealants, paints and plastic components

For reasons ranging from aesthetics to economics, other types of buildings use different materials. In general, commercial or industrial buildings use both more materials that incorporate industrial minerals and more prefabricated parts than low-rise housing, which is the class of building most bound by tradition.

In low-rise commercial structures, the frames are made from structural steel or concrete, with exterior walls of concrete block, precast concrete panels, glass, metal or clay-brick for cladding, and various forms of membrane roofing. Interiors are usually drywall construction using gypsum wallboard, but frequently employ steel rather than wooden studding. In general, utility and fire resistance, rather than traditional aesthetics, are dominant determining factors in the choice of materials for this type of building. Consequently, substantial portions of the structure of most small commercial and industrial buildings are made from industrial mineral products.

The earliest high rise buildings were frame structures in which the frame was used to support floors and walls of masonry or brick. The steel was embedded in the external walls, and panels were often infilled in the frame. In the past 25 years, the approach has moved to a curtain wall type of structure in which various forms of cladding are supported by, or attached to, the structural frame. These buildings may be designed either with a central core structure that carries services and around which floors are mounted supported by columns, or they are built using structural frames. Cores and floors are almost invariably made from reinforced concrete, as are many columns. Frame structures may be of concrete or steel, or in some cases, a combination of both (so-called composite structures), in which vertical elements are concrete with steel cross members.

The cladding materials — which may include stone, concrete, glass, aluminum, steel and brick — have the appearance of solidity associated with the structural stone or masonry walls of an earlier era. However, they are not used to support structural loads, this function being provided by the frame. In this way, the structural frame has provided the possibility of great variation in the form and appearance of buildings that no longer need to be contained inside a load-bearing envelope. As a consequence, a wide variety of wall materials is available to meet the needs of utility, economy and fashion, this being particularly apparent in the prestige buildings constructed by major public and private corporations in the centre cores of cities. The decorative interiors of these buildings also incorporate a myriad of materials, including polished stone, exposed concrete, drywall, glass block and plastic or metal panels. The emphasis in these buildings is usually on aesthetics, and the use of alternative building materials and building techniques has shown great imagination.

From this brief overview, it is clear that industrial minerals are an integral part of the construction and building products industries in Ontario, with many potential possibilities for development and change. As will be discussed in subsequent chapters, we are entering a period of rapid change and innovation in construction methods which will inevitably continue to place increasing demands on the building materials industry for new products. It is these demands for new materials and products that may present both potential opportunities for, and threats to, the Ontario minerals producers over the long term.

REFERENCES

1. "Summary Report: The Changing Housing Industry in Canada, 1946-2001," *CMHC Report NHA 6120 02/89*, (Canada, Mortgage and Housing Corporation, Ottawa, 1988), 54 p.

2. Industrial Minerals in Ontario

The following brief review of the status of the industrial minerals industry in Ontario is given to form a background to understanding the role played by industrial minerals in the construction and building products industries. For more detailed economic information on this subject, the reader is referred to the original sources, which includes the Ontario Ministry of Northern Development and Mines [1,2], Energy, Mines and Resources Canada [3], and published reviews [4-6].

Industrial minerals are, as we have noted, a broad and diverse group. Thus, any attempt to summarize the nature of the industry is bound to exclude some minerals of interest, while including others of little relevance to construction products. Our approach in this chapter has been to consider a broad group of minerals including those that, though not currently used in building products, may find such applications in the future.

CURRENT STATUS

Preliminary estimates of Canadian and Ontario mineral production during 1988 are summarized in Table 2-1. The total value of shipments in Canada reached $37.1-billion, up from $36.3-billion in 1987 [2]. The Ontario mineral industry shipped mineral products valued in 1988 at $7.2-billion (~19.3% of the national total), which was significantly increased from the $5.6-billion of shipments in 1987.

The distribution of minerals shipped varies from province to province depending upon the resources and markets available. The data in Table 2-1 show the distribution of value between four main economic classes of mineral products for Canada and Ontario in 1988. Comparisons within these data show that Ontario is primarily a producer of structural materials and metallic minerals. The Ontario minerals industry produced 45.6% of the total structural materials and 40.2% of the metallic minerals shipped in Canada in 1988.

Within the industrial minerals segment, production data for six principal non-metallic minerals and five structural materials are reported by the Ministry of Northern Development and Mines [1,2]. It is notable from these data (Table 2-2) that the value of shipments of structural materials far exceeds that of other non-metallic minerals, a feature not seen in the national data (Table 2-1). Structural materials are responsible for 82% of the value of shipments of industrial minerals in the province. Not only do these figures indicate the importance of industrial minerals to the Ontario economy, they also show clearly that structural materials for construction are a major factor in the province's industrial minerals sector.

Substantial growth has occured in both non-metallic mineral and structural materials production in Ontario over the past 20 years (Figs. 2-1 and 2-2). In particular, the production of structural materials in Ontario has grown rapidly since 1983, especially for stone products and cement (Table 2-3). This growth reflects the demands placed on the industry by the construction activity during this period and emphasizes the economic inter-dependence of building materials and industrial minerals. Most of the growth has resulted from increased volume of production. Some has resulted from inflation, and in some cases — for example, cement and clay products — selling prices have increased faster than the consumer price index, as can be seen from Table 2-4. Prices of other materials, such as concrete, sand and gravel, have fallen behind the inflation trend.

Ontario exports industrial minerals both to other provinces and abroad. Relevant export data, as reported by Energy, Mines and Resources Canada [3], are not disaggregated by province; also, they include products with mineral materials, and therefore count substantial added value. Thus, it is only possible to estimate the value of provincial exports indirectly. In 1986, exports of non-metallic mineral materials and products from Canada reached $3.8-billion. Of this total, $2.8-billion was shipped as crude unprocessed material, the remainder being in processed or semi-processed form.

A list of industrial minerals found in Ontario is given in Table 2-5.

TABLE 2-1 MINERAL PRODUCTION IN CANADA AND ONTARIO, 1988

	Canada		Ontario		Ontario as % of Canada
	Value ($000)	(%)	Value ($000)	(%)	
Fuels	17,840,144	48.1	85,118	1.4	0.5
Metallic minerals	13,790,038	37.2	5,543,442	77.3	40.2
Non metallic minerals	2,678,080	7.2	270,736	3.8	10.1
Structural materials	2,789,331	7.5	1,272,587	17.7	45.6
Total minerals	37,097,593	100	7,171,883	100	19.3

Source: ref. [2]

TABLE 2-2 PRODUCTION OF SOME INDUSTRIAL MINERALS IN ONTARIO, 1987 & 1988

	1987		1988	
	Quantity (000 t)	Value ($000)	Quantity (000 t)	Value ($000)
Non Metals:				
Barite	†	1,400	†	1,475
Gypsum	1,468	16,547	1,459	19,712
Nepheline syenite	506	20,664	542	23,411
Quartz	342	10,180	298	8,430
Salt	5,690	139,326	6,863	158,440
Talc & soapstone	†	9,632	†	11,870
Structural Materials:				
Clay products	†	120,209	†	122,203
Cement	5,432	419,713	5,411	449,025
Lime	1,601	108,485	1,660	114,374
Sand & gravel	96,251	280,725	99,650	288,985
Stone	59,925	280,711	58,900	298,000

Source: refs. [1,2] † not reported

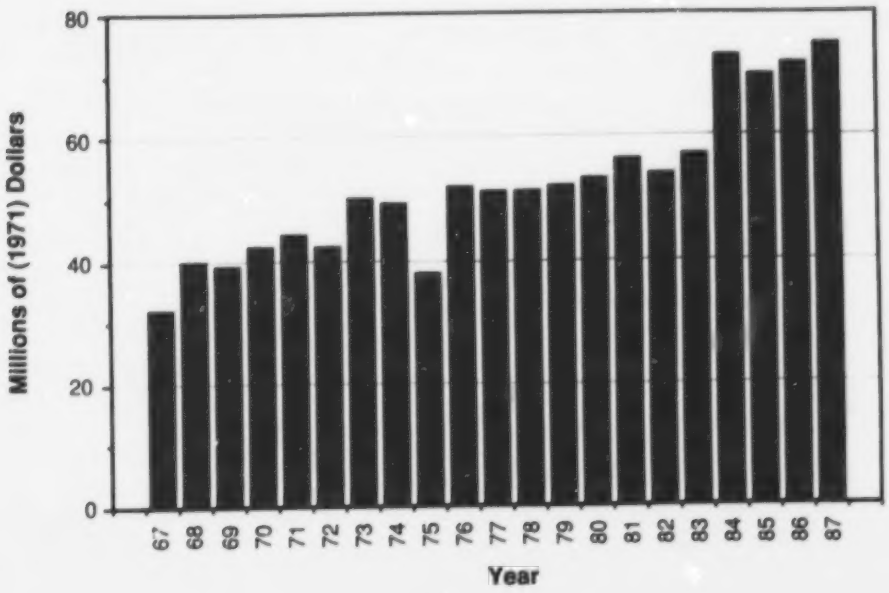

Figure 2-1 Growth of non-metallic mineral production in Ontario (constant 1971 dollars), 1967 to 1987. Source: ref. (1).

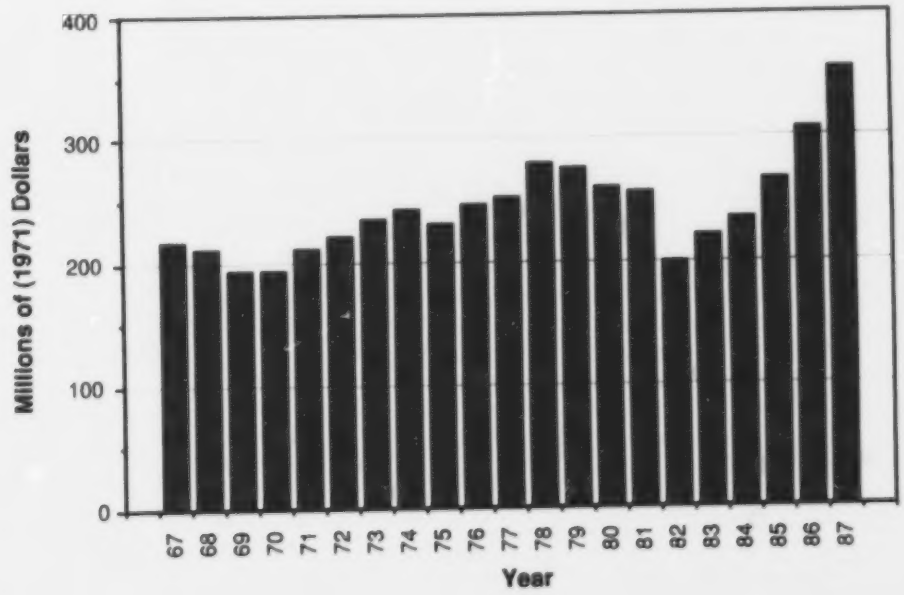

Figure 2-2 Growth of structural materials production in Ontario (constant 1971 dollars), 1967 to 1987. Source: ref. (1).

TABLE 2-3 GROWTH OF STRUCTURAL MATERIALS PRODUCTION IN ONTARIO, 1983–1988

	Value ($000)		
	1983	1988	% Growth
Clay products	75,430	122,204	62.0
Cement	229,850	449,025	95.4
Lime	89,546	114,374	27.7
Sand & gravel	123,000	288,985	134.9
Stone	117,000	298,000	154.7
Total	634,826	1,272,587	100.5

Source: refs. [2,4]

TABLE 2-4 SELLING PRICE INDICES FOR SOME INDUSTRIAL MINERALS AND MINERAL PRODUCTS IN CANADA, 1981–1986

	1981	1982	1983	1984	1985	1986
	(1981 = 100)					
Sand and gravel	100	109.2	108.8	108.2	109.4	111.4
Silica sand	100	110.5	117.2	114.6	118.4	121.7
Stone	100	112.8	123.6	127.5	133.8	138.9
• building	100	112.0	123.2	127.6	132.9	136.5
• crushed	100	114.9	127.6	134.6	143.3	151.0
• other	100	112.0	123.2	127.6	132.9	136.5
Insulating materials	100	110.6	112.7	113.4	120.8	121.8
Cement	100	117.9	123.7	128.0	133.9	137.4
Clay products from domestic clays	100	112.8	120.5	130.7	143.0	150.7
Glass	100	109.4	114.5	119.0	121.1	125.8
Concrete	100	111.2	115.0	113.8	114.0	120.3
Consumer Price Index	100	110.8	117.2	122.3	127.2	132.4

Source: ref. [3]

TABLE 2-5 INDUSTRIAL MINERALS FOUND IN ONTARIO

amethyst	fluorspar	nepheline syenite	soapstone
asbestos	gneiss (micaceous)	niobium	soda ash
barite	granite	phosphate	sodalite
beryl	graphite	potash feldspar	spodumene
black anorthosite	gypsum	quartz	talc
breccia	kaolin	rare earths	tantalum
building stone	kyanite	rose quartz	traprock
calcium carbonate	lime	salt	tremolite
cement	magnesite	sandstone	vermiculite
clay/shale products	marble	schist	wollastonite
dolomite	marl	serpentine	
feldspar	mica	silica	

Source: ref. [4]

INDUSTRY STRUCTURE

As the nature of industrial minerals is diverse, so is the structure of the industry that produces them. In Ontario, the industrial minerals industry may be conveniently described under three categories (Table 2-6) , reflecting the nature of the products and to some extent the size of the companies involved, as follows:

(1) Manufacturers of building materials — namely, gypsum, cement and clay products — that are included among industrial minerals are generally large, vertically integrated, multinational companies. They produce minerals and process them into products that are distributed to the construction industry. Overall, they are involved in significant addition of value to the minerals that they recover. These companies are few in number, and most operate more than one mineral recovery and processing facility located close to major construction markets across the province. They frequently own other associated businesses such as aggregate production and concrete manufacturing.

(2) Producers of stone products fall into two groups — companies that quarry dimension stone and often also produce crushed stone aggregates, and those that recover sand and gravel. These companies vary widely in the size of their operations. Some are integral parts of the large building materials manufacturing organizations, while others are small private operators of local sand pit or stone quarries. The products are usually shipped with minimum processing either directly for use in construction, or to other organizations that add value and market finished materials to the construction sector.

(3) A diverse group of specialty minerals are produced for industries largely outside of the construction materials. These include lime for steel and agricultural purposes, silica for refractories, and fillers for plastics. In general, the products from this group are subject to considerable addition of value by processing at the source. Some of the producers of these minerals are large multinational or nationally owned resource companies; others are small operations producing single specialty products.

More detailed discussion of the structure of the industry is given in relevant sections of Chapter 5 of this report as part of our examination of applications for minerals in building products.

CHANGE AND INNOVATION IN INDUSTRIAL MINERALS

Many industrial minerals are consumed by traditional, long-established industries. This has led to a general tendency for mineral producers to conduct little research and to respond largely to new opportunities on a market-pull basis. Among the three groups of mineral producers noted above, the building materials segment tends to be innovative in the development of new products and production technology, though much of the research is conducted out of the

TABLE 2-6 SUMMARY OF INDUSTRIAL MINERALS PRODUCERS IN ONTARIO

	No. of Operations	Total Production (1988) Value ($000)	Quantity (tonnes)
Building materials			
Gypsum	3	19,712	1,459,000
Cement	5	449,025	5,441,000
Clay products	17	122,203	n/a
Stone Products			
Quarried stone	32	298,000	58,900,000
Sand and gravel	37	288,985	99,650,000
Miscellaneous specialty minerals			
Lime	8	114,374	1,660,000
Barite	1	1,475	n/a
Lizardite/serpentine	1	n/a	n/a
Nepheline syenite	1	23,411	542,000
Quartz	2	8,430	298,000
Soapstone and talc	2	11,870	n/a
Calcite fillers	1	n/a	n/a
Tremolite	1	n/a	n/a
Traprock	1	n/a	n/a

Source: compiled from data in ref. [2]
n/a, not available

province and in many cases off-shore. The specialty minerals producers, unless they are captive producers for specific manufacturing process industries (e.g. lime for steel production), must innovate to meet the diverse demands of their clients. Fillers producers, though market-driven to a large degree, usually maintain a close relationship at the technical level with users of their products. A similar situation exists for suppliers of minerals to the chemical industries. In some cases, new technology has been developed in advance of markets, often in conjunction with other material producers. Two examples are the development of nickel-coated mica by Sherritt Gordon Mines Limited and Lacana Mining Corporation, and nickel-coated graphite by INCO. Among stone producers the low unit-value and low value-added nature of the product leaves little opportunity for innovation or research. Developments in these areas have tended to come from European sources, the technology from which is starting to be imported into Canada.

Overall, from an examination of the present mineral shipments and the structure of the industry, it is apparent that the major existing market for industrial minerals already resides in construction and building products. Thus, at the outset, it can be assumed that opportunities for the industry as a whole to increase the volume of industrial minerals used in building will lie in six areas:

- Increased shipments of established mineral-based products to meet any general increase in demand from the construction sector;
- Increased market share by displacement of building products made from other materials (for example, wood or steel);
- Increased market share by displacement of imported minerals or products;
- Increased exports;
- Introduction of new products based on industrial minerals, and the development of new uses for minerals not widely used by the building industry;
- Maintenance of market share in the face of competition from other materials such as aluminum or plastics.

A general overview of the size and structure of the industrial minerals industry in Ontario reveals that the industry is divided between numerous producers of minerals and mineral-based products, many of which are used in construction. Historically, the industrial minerals producers have always been major suppliers of materials to the construction industry. In Ontario, ~82% of the total production of industrial minerals is in the category of structural materials. In Part II of this report, the more important segments of the industry are discussed in detail as consideration is given to building products on a sectoral basis.

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3. Construction in Ontario

The needs of the construction sector are changing. While many of these needs remain the same as they have for decades, even the most casual observation of construction activity shows evidence of changing practices, from which it may be inferred that over the next few years the industry will experience changing materials needs. The industrial minerals producers of Ontario will do well to examine the directions being taken by building technology over the next decade or so, and in particular, opportunities that may arise for supplying new building materials or products.

It is necessary to outline the status of the construction industry in Ontario to provide a part of the background for understanding the important role construction plays in the use of industrial minerals in Ontario. A number of public sources provide useful background information of this type: Statistics Canada [1], the Ontario Ministry of Northern Development and Mines [2], Energy, Mines and Resources Canada [3], the Ontario Ministry of Housing [4-6], the Ontario Ministry of Treasury and Economics [7], the National Research Council of Canada [8] and various reports published in the past five to ten years [9-12]. The reader is referred to these original sources for a more detailed economic analysis of the industry.

CURRENT STATUS

For the purposes of this overview, the construction industry may be defined as that part of industry that conducts the entire construction process, including conceptual design and financing, through manufacturing and assembly, to maintenance of the built environment. Defined in this way, construction is the largest single industry in Canada, and is reportedly the second largest goods-producing industry in Ontario, accounting for about 5% of gross domestic product (GDP) and employment in the province. Approximately one-quarter of the value of construction in Canada takes place in Ontario [7].

The Canadian construction industry has produced a capital stock valued in 1980 at more than $1100-billion [13,14]. It is an industry that converts financial investment and raw materials into physical assets: houses, office towers, factories, roads, bridges, and other elements of the national infrastructure. In 1987, the total value of work put in place in Canada by the construction industry was ~$80.9-billion, or about 14% of the GDP (Table 3-1). According to Statistics Canada [1], the contribution to this total from the Ontario construction industry was valued at $30.2-billion.

As noted in Chapter 1, construction activity is conventionally separated into two parts — building construction and engineering construction — of which this report is concerned only with building construction. Of the $80.9-billion in Canadian construction put in place in 1987, $57.2-billion (~71%) was classed as building construction. Of this, $24.1-billion (~42%) was contributed by the Ontario industry (Table 3-1).

Nationally, more than 640,000 people were directly employed in construction in 1985 [15], a figure that is increased to 1.5 million when those employed in the manufacture, sale and transportation of construction materials are included [16]. According to a recent review of activities by the Ontario Building Industry Strategy Board, construction is the largest employer in the province [5]. In 1985, building construction employed twice the labour force of agriculture and three times that of automobile manufacturing [5]. Paradoxically, in spite of this dominance, the industry faces a continuing problem with unemployment [17]. In 1985, unemployment in the industry was reported to be about 20% and was the highest of all economic sectors [5]. Despite the continuing building boom in Central Ontario, the average construction unemployment rate for the province was 8.1% over the 12-month period ending April 1988 [17].

As construction can be subdivided between building and engineering products, so can the different products of the building segment be categorized. Statistics Canada recognizes five categories of building construction: residential, industrial, commercial, institutional, and other building. Historically, of these, residential construction has been the major component, with commercial construction in second place. Nationally, 60% of the value of building construction was in the residential category in 1987 (Table 3-2). The historical pattern of the division of building construction between residential and non-residential categories is shown for Ontario in Fig. 3-1, and may be compared with similar national data (Fig. 3-2). It is evident that recent trends in Ontario have been towards a larger proportion of building construction going into housing.

TABLE 3-1 VALUE ($000) OF CONSTRUCTION IN CANADA BY PROVINCE, 1986-88

Province	1986 Building Construction	1986 Engineering Construction	1986 Total	1987 Building Construction	1987 Engineering Construction	1987 Total	1988 Building Construction	1988 Engineering Construction	1988 Total
Newfoundland	802,442	809,153	1,611,595	878,732	696,895	1,575,627	898,710	664,234	1,562,944
Nova Scotia	1,493,407	872,077	2,365,484	1,694,516	715,721	2,410,237	1,752,532	785,781	2,538,313
New Brunswick	1,042,640	428,756	1,471,396	1,178,179	465,024	1,643,203	1,229,301	470,882	1,700,183
Prince Edward Island	223,287	70,364	293,651	222,907	72,148	295,055	241,763	86,388	328,151
Quebec	11,690,251	3,888,916	15,579,167	13,971,089	4,158,213	18,129,302	13,799,399	4,888,767	18,688,166
Ontario	19,480,274	5,824,510	25,304,784	24,148,448	6,061,990	30,210,438	24,509,690	6,807,027	31,316,717
Manitoba	1,870,090	928,101	2,798,191	1,992,684	942,052	2,934,736	2,033,533	1,154,802	3,188,335
Saskatchewan	1,563,702	1,396,406	2,960,108	1,808,053	1,502,338	3,310,391	1,792,538	1,732,571	3,525,109
Alberta	4,109,233	6,239,982	10,349,215	4,775,800	5,663,670	10,439,470	4,892,445	7,048,038	11,940,483
British Columbia, Yukon and N.W. Territories	5,151,540	3,815,498	8,967,038	6,557,677	3,349,923	9,907,600	7,126,702	3,363,932	10,490,634
Canada	47,426,866	24,273,763	71,700,629	57,228,085	23,627,974	80,856,059	58,276,613	27,002,422	85,279,035

Source: Statistics Canada, quoted and compiled in ref. (3a); actual expenditures 1986, preliminary actual 1987, intentions 1988.

TABLE 3-2 VALUE OF BUILDING CONSTRUCTION BY TYPE IN CANADA, 1987-89

	1987	1988 ($ millions)	1989
Residential	35,825	38,660	39,295
Industrial	3,244	3,560	3,678
Commercial	12,378	13,580	14,289
Institutional	4,313	4,512	4,968
Other building	2,147	2,415	2,848
Total	57,907	62,727	65,078

Source: Statistics Canada (ref. [3b]); actual expenditures 1987, preliminary actual 1988, intentions 1989.

As would be expected for a province of such a size and with such diverse economic characteristics, construction activity in Ontario varies greatly from one region to another, both with respect to total value (Fig. 3-3) and the relative portion dedicated to residential versus non-residential property (Fig. 3-4). Central Ontario, including the Toronto, Hamilton, Oshawa and Kitchener areas, accounts for most of the building activity in the province (70%). Northern Ontario has accounted for only 5-8% of building activity over the past two decades.

No major industry exists in isolation from the economy as a whole, and construction is not an exception. The construction industry purchases goods and services from a range of other sectors [4]. Consequently, investment in construction has a net effect on other sectors through economic "linkages" [16] — for example, for each $100 of construction cost, the industry spends $36 on materials, $32 on labour, $17 on purchase of services, and $5 on taxes; $10 goes towards profits [18]. The 1980 Canadian Input-Output Tables [18] indicate that for each dollar spent in

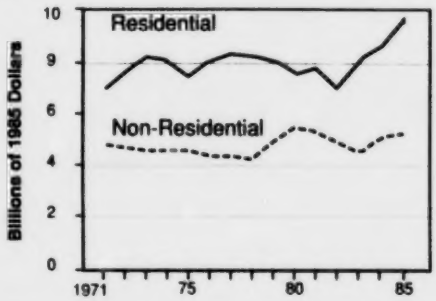

Figure 3-1. Real building construction expenditures by type of work, Ontario 1971–1985. Source: ref. (6).

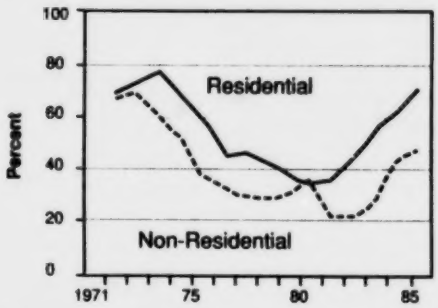

Figure 3-2. Residential and non-residential building expenditures, Ontario as percent of Canada 1971–1985. Source: ref. (6).

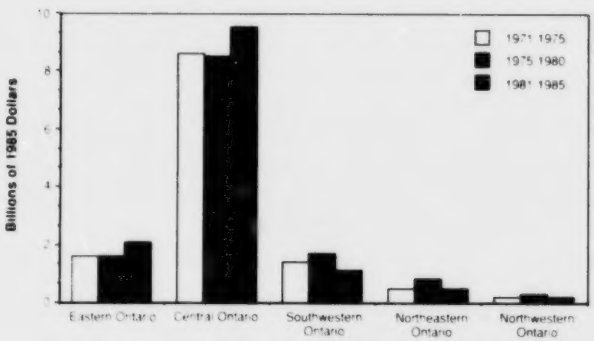

Figure 3-3 **Average annual building construction expenditures by region, Ontario 1971–1985. Source: ref (6).**

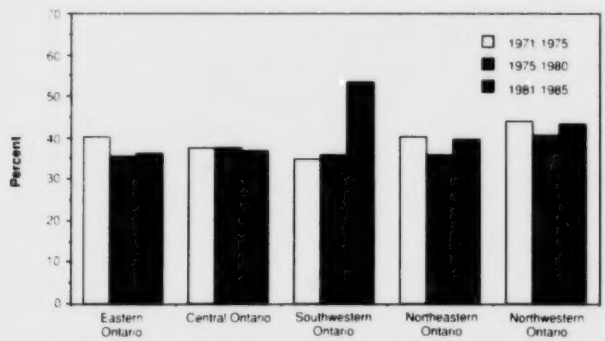

Figure 3-4 **Average annual non-residential building construction expenditures as percent of total building expenditures by region, Ontario 1971–1985. Source: ref. (6).**

construction output, a multiplier effect worth $1.83 is generated in the whole economy. This is compared with $1.72 for agriculture, $1.95 for most manufacturing industries, $1.70 for transportation, and $1.56 for business services [18].

The economic multiplier effect generated by the construction industry in Ontario also has a major impact on employment in other sectors. Not only does the industry draw goods and services from within the province, but construction in other provinces generates demand fulfilled by Ontario, as well. According to the Economic Council of Canada [19] in the 1970s, 47% of the construction material needs of the Atlantic Region were met by Ontario. In this respect, Ontario is an exporter of construction materials and services.

Although construction remains a major part of the Ontario economy, it has accounted for a smaller share of the GDP in the 1980s than in previous decades. A similar trend is seen nationally (Fig. 3-5). The declining importance of building construction results from a relatively slow rate of growth in real spending on building compared with real economic growth (Fig. 3-6). Two factors thought to be responsible for the general decline in the relative proportion of the GDP expended on building construction have been identified [16]. First, demographic changes in Canada have led to a declining rate of population growth, with the consequence that the population is aging. As a population ages, household formation slows. These trends are expected to continue for the next 10–15 years. The demographic factors have more impact on housing than on other types of construction. Secondly, economic factors, such as the general level of economic activity, disposable income, interest rates, and inflation levels, and external factors such as world oil prices, all influence general construction activity.

The declining share of the national economy going to the construction sector points to a need for expanding export activity [16]. This has been recognized in Ontario and incorporated into the five goals for the Building Industry Strategy Board [5], one of which is "to promote export development and import replacement." At the present time, the construction industry is responsible for some limited level of exports. In manufactured housing, companies in Alberta and Ontario have established markets in the United States [16]; and Canadian consulting engineers, builders and architects are gradually making inroads in foreign markets [16]. According to Canada Constructs [9], in 1984, 20% of the revenues of consulting engineers in Canada were derived from foreign operations. One source is quoted as reporting that in 1984, Canada had 8% of the world market for consulting engineering services [16]. Large developers based in Canada have a major share of their operations in the United States, notable examples being Olympia and York Developments Ltd., Trizec Corporation Ltd., Bramalea Ltd., Cadillac Fairview Corporation Ltd., and Campeau Corporation.

The recent free trade agreement between Canada and the United States raises questions of its impact on the construction industry. On this issue, Rakhra noted in 1986 [16]:

"Sources in the Canadian construction industry feel that free trade with the U.S. will not significantly impact on construction exports and imports. Even at present, all markets for the construction contracting business are fairly open... From discussions with other industry and government sources, it seems clear that free trade with the U.S. will not produce serious consequences for the construction industry; rather elimination of Canadian and U.S. tariffs will result in 2000 additional jobs by 1995 in export-related activities in construction (private source)."

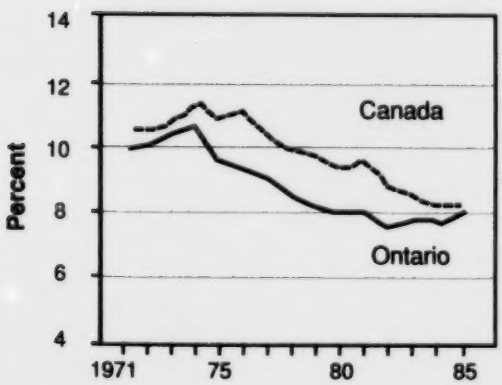

Figure 3-5. Building construction expenditures as percent of GDP, Ontario and Canada 1971-1985. Source: ref. (6).

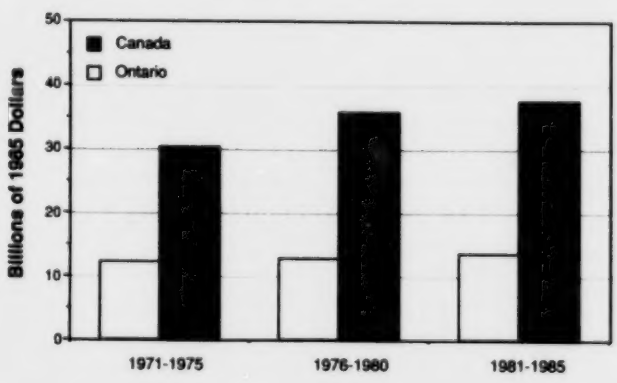

Figure 3-6. Average annual real building construction expenditures, Ontario and Canada 1971-1985. Source: ref. (6).

While the overall level of construction activity has fallen in comparison with other forms of production, a notable trend in the nature of construction has been the rise of real spending on repair and renovation, in proportion to expenditures on construction as a whole (Fig. 3–7). This reflects the consequences of the aging of the building stock and the infrastructure that has been built in the past 20 to 50 years.

With respect to future levels of construction, in the residential sector, housing starts are expected to decline in the next 20-year period, the extent of which is claimed in a recent CMHC report [11] to depend upon the level of immigration during this time period (Table 3–3). Commercial construction has been exceptionally strong, particularly in the Toronto area. Projections are that the beginning of a cyclical decline in commercial starts will come in 1989, reflecting a general weakening of the economy [20].

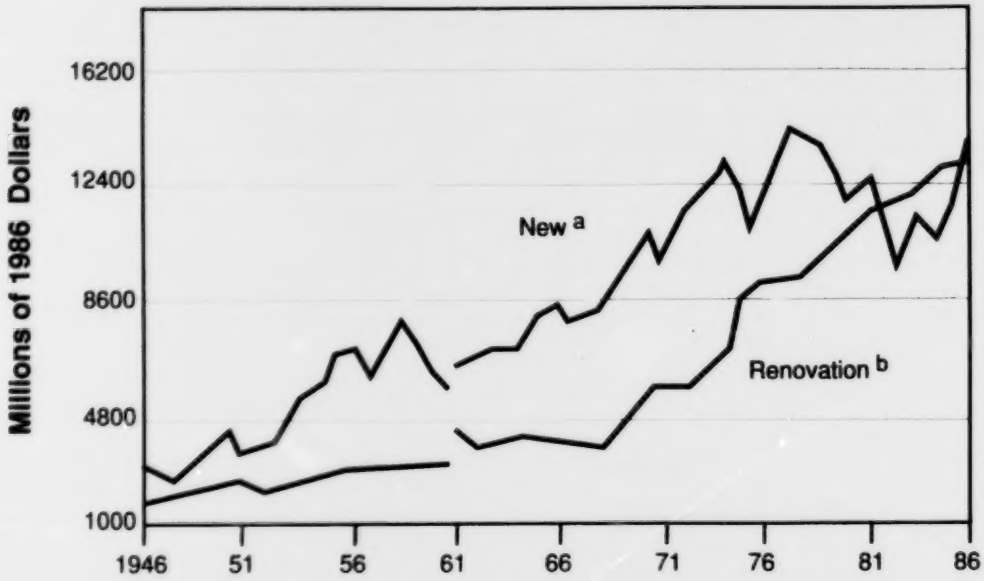

Figure 3-7 **Real residential construction expenditures by component, Canada, 1946-1986. Note there is a break in the time-series data in 1961. a, excludes supplementary and land costs; b, includes repairs (repairs for the 1946-1952 period are estimates). Source: ref. (11).**

TABLE 3-3 **AVERAGE ANNUAL DEMAND FOR NEW HOUSING, CANADA, 1981-2001, DWELLING UNITS (000S)**

	Low Immigration Constant Headship Rates	High Immigration Constant Headship Rates	Low Immigration Rising Headship Rates	High Immigration Rising Headship Rates
Actual*				
1981-1986		156.5		
Projected				
1986-1991	170.5	182.5	194.5	205.5
1991-1996	146.0	179.0	162.0	195.0
1996-2001	127.5	180.5	144.5	198.5

Source: ref. [11]; note: includes mobile homes.
* Approximated by housing completions and estimated mobile home shipments.

Since 1970, there has been a general decline in new institutional construction. Projections are for a gradual increase in school construction spending and a significant increase in demand for health care facilities.

INDUSTRY STRUCTURE

In contrast to its huge size and economic importance, the Canadian construction industry is highly fragmented and complex. According to Statistics Canada, in 1985 there were 111,000 construction firms in Canada, 90% of which had 20 or less employees. Ninety-five percent had gross operating revenue less than $1-million and, in combination, produced less than 35% of the total contracting work performed [16].

There is considerable specialization of activity in most areas of construction, as seen in the 1985 data: 14,000 firms specializing in residential and non-residential building; 3,000, in heavy engineering and road building; and 94,000, in mechanical, electrical and other special trades [16]. The industry is thus still heavily weighted towards the small, trades-centred operation that has dominated it through its history.

Compared with some other industries, levels of foreign control over Canadian construction are relatively small. The foreign-controlled share of the non-financial assets, sales and profits of the industry was reported in 1986 to be 7.1, 5.7 and 4.8%, respectively [21]. This may be compared with the average for Canadian manufacturing as a whole, for which the corresponding levels were 43.8, 49.0 and 49.1%.

Certainly, in part, the fragmentation of the construction industry contributes to one of its main problems — low productivity. In December 1983, the Construction Industry Development Council completed a report entitled "Canada Constructs — Capital Projects and Canadian Economic Growth in the Decades Ahead [9]." In this report, productivity was identified as a major concern of the industry. Also in 1983, the Economic Council of Canada (ECC) reported that productivity growth throughout Canadian industry had "...sunk so low that it had no historical parallel [22]." As applied to construction, econometric studies published in 1979 [23] showed that in the period 1957-1975, labour productivity in construction grew at an annual rate of 1.65%, compared with 3.27% for manufacturing, 6.53% for mining and 2.72% for trade. Only finance and real estate recorded lower growth rates (0.63%) than construction [23]. The Canadian Committee on Building Research has noted:

> "...efficiency has a direct bearing on the cost of new production facilities, infrastructure, shelter and the viability of capital projects in general. A reduction of a few percent in productivity on a major project means many millions of dollars in extra costs; similarly, an improvement...will result in immense savings."
>
> Revay and Associates [24]

The ECC study [22] analyzed the sources of productivity growth in various sectors of the economy under a number of categories including "technical progress," which was found to contribute about 70% to labour productivity growth in the construction sector. This analysis, though now ten years out of date, indicates strongly the important role that technology must play if the construction industry is to substantially increase its level of productivity.

TECHNOLOGY AND THE PROCESS OF CONSTRUCTION

Current technology, as applied by all types of industry, is built upon the accumulation of knowledge from the past, much of which comes directly from investment in research and development. Construction is an industry that developed almost to its present state before the rise of modern technology. Thus, in many ways, the influence of tradition on building practices and the acceptance of materials is stronger than the influence of technical development. Overall, the industry has accepted change largely as a result of "market-pull" rather than "technology-push" factors. Writing in 1970, Moshe Safdie [25], the architect of Montreal's Habitat '67, noted:

> "Working on Habitat I became increasingly aware of a basic shortcoming of the building industry. Its whole tradition is to build with what materials happen to be available. Every other industry defines its requirements and then develops the material best suited to the problem. They don't design an aircraft with steel just because they happen to have steel handy: if they come to the conclusion that they need a metal that's lighter, then they perfect the manufacturing of aluminum...
>
> "I would say that as a rule industry, where it has the resources and organization, develops materials to meet a given specification...
>
> "But because of its organizational structure, its method of operating, and its fragmentation, the construction industry has neither the circumstances nor the resources to do the same and consequently has always used leftovers; it has used steel, aluminum, fiberglass after they were developed elsewhere. I don't think technologies are directly transferable from one industry to another. Each realm of manufacturing has its own specific needs. It can't just borrow — yet that's what the construction industry has been doing."

For the vast majority of circumstances, this criticism is as true in 1990 as it was in 1970. Yet, it seems from some of the developments in building materials over the past decade that when it is faced with strong motivation the building industry can develop materials "best suited to the problem."

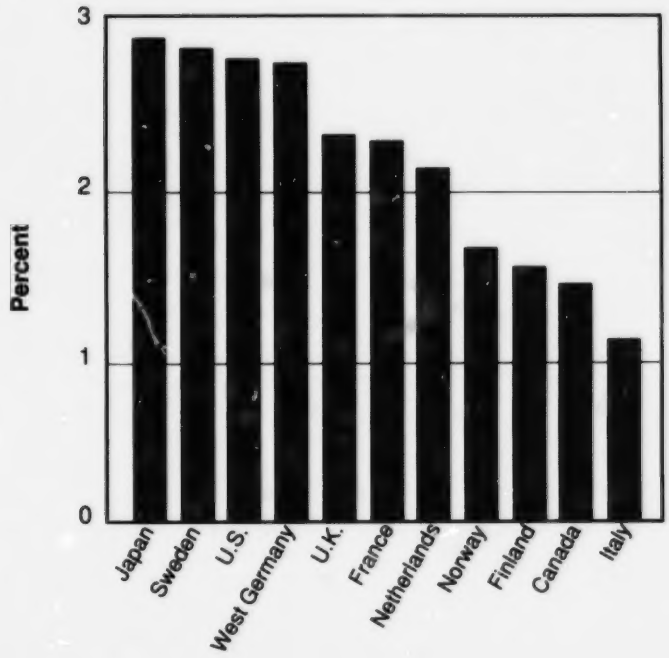

Figure 3-8 **Comparison of research and development funding in different countries as percent of national output. Source: ref. (27).**

The importance of technology to construction is evidently appreciated by many of the industry's practitioners. Revay and Associates [24] report that "...two-thirds of the major issues identified by industry spokesmen have significant or vital technological implications." Yet the industry spends only 0.1% to 0.2% of the value of total construction output on research, compared with 1.43% for the total economy [16].

> "The construction industry has not undertaken any significant level of R&D expenditures itself. It benefits, however, from work done by machinery, and equipment manufacturers, the producers of building materials and components, and government organizations such as the NRC."
>
> Revay and Associates [24]

> "...marked by a dwindling domestic market, and slowly growing productivity, it lags behind other industries in generating and adopting new technology."
>
> Rakhra [16]

This should be contrasted with the Japanese construction industry which as a whole invested 0.5% of sales in R&D in 1986. The Shimizu Corporation alone spent the equivalent of $74-million (U.S.), equal to 1.1% of annual sales. The so-called "Big 6" Japanese contractors have increased R&D expenditures at an average annual rate of 9% for the past several years [26].

In part, the low level of research by the industry reflects the fact that Canada as a nation, and Canadian industry in general, lag far behind other "advanced" countries in expenditure on research and development in science and engineering (Fig. 3-8). Canada spends only 1.43% of the GDP on research and development, ranking 10th among industrialized nations. Of this, industrial R&D accounts for only 0.65% of the GDP [27].

Not only is the construction industry fragmented, but it is constantly changing at the operating level. Ruberg and Sander [28] have noted that for each building project, the individuals and sectors involved in the building process are structured into a team. However, once the building has been completed, the team is largely dissolved. In this constant state of organizational change, technical innovation comes slowly.

The Economic Council of Canada report "The Bottom Line" [22], records the importance of industry structure in determining the rate at which innovation diffuses. The presence of many small firms tends to slow the process because of difficulties experienced in obtaining and applying information. Larger, more specialized firms tend to adopt innovations more quickly and are better able to manage the necessary financial risks. Evidence is also cited [22] that the nature and extent of technology transfer to firms in Canada vary greatly depending upon whether they are Canadian or foreign-owned. Foreign-controlled firms have been found to acquire technology from external sources to a much greater

extent than Canadian-owned organizations. In both respects, much of the Canadian construction industry is not well placed to gain access to and accept new technology.

Acceptance of innovation by the construction industry is affected by three factors [28]:

- *Technical feasibility* — The means to apply the technology must be available at an advanced level, not in a developing stage that requires acceptance of technical risk.
- *Economic impetus* — Overall, the motives of the construction industry for accepting technical change have been cost reduction and increased profitability, usually gauged on a short-term basis.
- *Institutional and cultural acceptance* — The technology must fit the existing styles of work and organization. Innovative technology may not be acceptable to the strong trade-union building delivery organization. Codes and standards can work for or against innovation.

These issues must be addressed if industrial minerals producers wish to encourage the construction industry to accept new materials or to develop the changed building techniques upon which opportunities for new materials will rely. The first task of this report is to identify in broad terms the trends in the construction industry and its marketplace that are most likely to give economic impetus to the industry to accept new developments, many of which are both technically feasible and available.

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4. The Market for Industrial Minerals in Construction

In the first three chapters of this report we have discussed the nature, the status and some of the problems of the industrial minerals and construction industries in Ontario. In general, though these industries stand at the front and back of the construction process, they interact only indirectly through the intermediate manufacturing of *building materials*. This chapter is intended to provide the reader with a perspective on the vast amounts of information available on building products and the possible role of industrial minerals, by first identifying the underlying structure and trends in the Ontario construction materials marketplace. With this as a basis, the next chapter will examine the technical nature of the sectors of the building materials manufacturing industry involved in the processing of industrial minerals. Possible strategies to increase the value gained from the use of industrial minerals in building products are considered in Parts II and III.

MARKET STRUCTURE

As will be seen in Part II, the process of supplying building products to the construction industry is a complex process, a general illustration of which is given in Figure 4-1. Three types of organizations are involved in the production and shipments of industrial minerals:

- Individual producers of minerals that are shipped with little value-added, notable examples being stone and aggregate products.
- Individual producers of specialty minerals, some of which are used in construction products.
- Divisions of integrated building products manufacturing companies, or vertically integrated construction organizations, that are responsible for mineral recovery from sources owned and operated by the parent company; typical examples are the recovery of raw materials for the production of cement, wallboard or clay products.

In general, these different types of mineral producers ship their products to different consumers. Low-value industrial mineral products are frequently sold by independent producers directly to builders — generally, these are products such as aggregates that will be used in construction work without further processing. The same group of producers also sells unprocessed materials to manufacturers (such as concrete or asphalt paving producers) who will add further value prior to the product reaching the construction site.

In these cases, the producer-customer relationship is relatively clear, and the industrial mineral is accepted on the basis of a specification defined either by the contractor or the manufacturer.

Many industrial minerals are subject to some degree of processing by the producer. They are then sold as a commodity (in competition with materials from other sources) to a manufacturer who adds further value and ships a finished product to the builder. Typical examples would be minerals used as extenders and fillers in plastic or asphalt products, silica for the production of glass, or lime for inclusion in the manufacture of ceramic or cemented products. Again, the producer-customer relationship is relatively clear, with specification of the mineral product being the responsibility of the manufacturer of the end-product.

Large quantities of industrial minerals are extracted and processed by vertically integrated companies that mine or quarry the mineral, convert it to an intermediate material, and ship the final value-added product to the construction operation, in competition with similar products from other sources. All stages in this process are handled by divisions or members of the same company group — for example, aggregates are quarried by concrete producers that themselves are owned by cement manufacturers; gypsum is mined for production of wallboard; limestone and shale are recovered for the manufacture of cement (itself often sold to concrete companies owned by the manufacturer); and clay is recovered at the brick or pipe plant for manufacture of heavy clay products. Within this complex structure it is often difficult to define who is the producer, who is the manufacturer, and which of the many intermediate entities in the process is the customer.

Similar complexity exists at the other end of the building process. While the builder may be responsible for delivery of the end product — the building — he may not be responsible for selection of the materials used in its construction, and he may not be the primary motivator of any

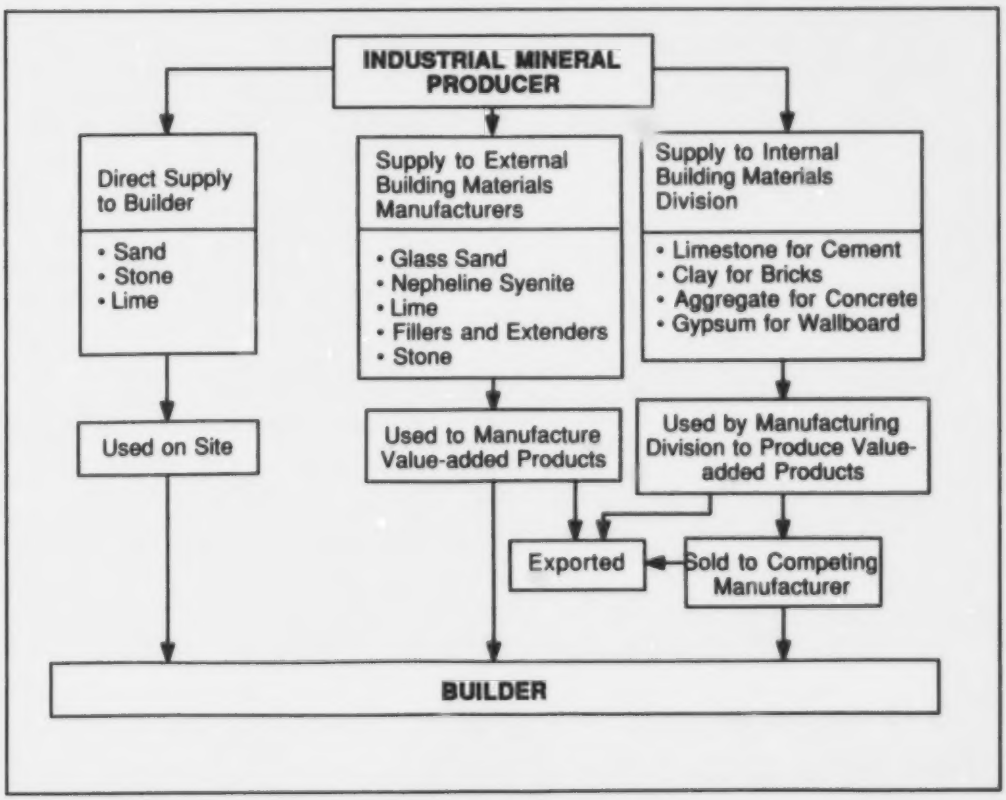

Figure 4-1 **Examples of the types of corporate interactions involved in the marketing of industrial minerals into the construction industry.**

changes or trends affecting building materials. If we are to identify strategies that the industrial minerals producer can follow, it is important first to understand who the decision makers are in the marketplace. Are they the integrated building materials manufacturers, the contractors, the building designers or the ultimate owners of buildings?

Information from some recently reported evaluations of the construction marketplace [1,2] suggests that the extent of participation of the contractor, the designer/specifier and the owner as consumers of building materials depends largely on the type of structure involved. For the purpose of this discussion, two building types can be distinguished: owner-occupied, low-rise single family housing; and structures built for the public industrial, commercial, institutional or high-rise residential markets. The role of the owner in these markets differs significantly.

In the low-rise residential market, as a recent report prepared for CMHC has stated [1], the buyer plays a minor role in determining the products and processes used in the construction of houses. In addition, the same report notes an indifference on the part of the house buyer to considerations of such issues as life-cycle costs that work against higher-priced innovations to improve durability or reduce energy costs. The key individuals in the selection of materials and design factors are the contractor and the sub-tradespeople [1]. Thus, in this market, the contractor or builder is the customer for building materials.

In the commercial market, including some of the high-rise residential sector — much of which is built for rental — the situation is wholly different. At a recent conference in Toronto, Quinn stated [2]:

> "In today's market, the owner is very involved in the whole building process. Whether (as) a corporation or an individual... there is usually one powerful individual that you have to deal (with)..., and on that individual, the ultimate responsibility lies... The professional team, by and large, recommends and reports to a sophisticated individual (who exercises ultimate authority)."

Thus, in contrast to housing, the owner of a commercial structure, backed by a design team, assumes the role of the customer.

In the case of the commercial structure, the owner is an investor who knows what returns to expect from a building, both in the short and long term. The costs of construction are also known on the basis of experience [2]. In this respect, security comes from *avoiding* any new factors: "...change equals innovation equals risk [2]." For a risk to be accepted, it must be worthwhile — that is to say, profitable. In this environment, though there will be a strong element of conservatism, there is strong awareness of other factors that influence profit, such as life-cycle cost, durability, and the competitiveness of a building as a rentable investment.

In dealing with these two market segments, the supplier of building materials is confronted with two wholly different groups of people, each concerned with different types of problems. However, we can look in detail at the factors that dominate decisions regarding innovation in construction. They are the same: "...money and security," according to Quinn [2]; and "...a primary incentive to reduce costs to the builder," according to Hickling [1]."

The first characteristic of the market for building materials may thus be defined as one involving a conservative approach to sustaining a balance between profit and risk. In the case of home construction, the risk is low and the profit, on the whole, is that of the contractor. In commercial construction, the profit is largely related to the life-time return on investment to the owner, while much of the risk lies with the professional design team [2].

In summary then, there are four types of customers for building materials:

- The contractor, particularly in house construction, with an interest largely in immediate financial return.
- The commercial property builder who must provide a product at an acceptable price.
- The team that must design a building and specify the materials of construction to meet the needs of the owner for construction-cost, life-cycle cost, aesthetics and rentability.
- The owners of commercial buildings who must decide, from the many options offered by the design team, those that yield the best return on investment.

We propose that these four groups constitute the people who will determine the directions in which building practices will change.

The contractors, either in housing or commercial building, face concerns related primarily to the cost and productivity of labour, the cost of materials, and the volume and stability of the market for construction. Thus, they are likely to be concerned with changes in materials or building practices that influence these factors. Accordingly, building products designed to reduce labour costs or materials costs are the most likely to prove acceptable to this group. Overall, the concerns of this group are similar to those identified in Chapter 3 as internal problems of the construction industry. To this extent, the building products market in this sector is driven more by the economic needs of the construction industry than by those of building owners.

To the cost factors, building designers must add concerns with the problems of meeting complex schedules, durability and aesthetics; while the owner/investor must also add consideration of the acceptability of the building as a rentable structure. Innovations in materials and practices that speed up construction, increase rentable area, extend

durability and lower maintainance costs, give aesthetic appeal, and provide for safety and comfort, are likely to be marketable to these groups [2,3-6]. In this sector, the building products market is driven both by the needs of the construction industry and by the needs of the owning/ investment community, the latter being strongly influenced by their customers and tenants. Because of its sophistication, this group also responds to some "technology push."

Satisfying the needs of these different groups will largely determine the future direction of construction technology, some indications of which are apparent in trends developing in Canada and elsewhere.

TRENDS IN CONSTRUCTION

Change, especially technological change, may be seen in many ways in an industry as complex and fragmented as construction. In an effort to identify trends in construction technology that may affect the nature of the materials used, two types of changes have been considered:

- Short-term changes resulting from the influences of such factors as the business cycle or consumer fashion.
- Long-term and radical changes in the ways in which buildings are constructed, or in changes in demand for different types of buildings.

As noted in the previous chapter, construction is a strongly cyclical activity; thus, short-term changes in total construction activity constantly affect the consumption of building materials. Consumer-driven fashions also tend to change on a short-term basis and may cause a market demand for new materials or, more likely, influence a redistribution in the market-shares of established materials. The forces of fashion, aesthetics and costs are likely to precipitate minor changes in market share between traditional materials that compete within the functions they serve in structures. Overall, these changes will likely be met by minor adaptations in their use or properties. For the purposes of this report, we have opted to give little consideration to short-term trends. While they are of great current significance to established suppliers of building materials, any strategic development of products would probably take too long to meet the needs of short-term trends.

Of greater importance in the present context are the long-term trends that will set the patterns of building processes for the next decade or so. In comparison with the factors determining short-term changes, much stronger forces rooted in the values and economic needs of an increasingly influential, consumer-oriented construction market may cause fundamental changes in the directions taken by the building industry [7]. If this is the case, some of the construction practices needed to meet these changes will not be possible without developing or adopting new materials and practices. These are the factors that will lead to new opportunities for the suppliers of building materials.

Because the construction industry is largely market-driven rather than being led or pushed by technology, it is difficult to predict trends that may serve to substantially influence its progress over the next decade. However, if our report is to serve its purpose, we must seek a perspective on the industry that permits some strategic judgments to be made by the producers of industrial minerals. We have chosen to use two guidelines, in the nature of assumptions, to identify significant trends:

- Firstly, we have assumed that the construction industry will endeavour to resolve some of the organizational and marketing problems that have been identified over the past few years.
- Secondly, we have assumed that some general trends identified from statistical reports and discussed by others in the industry are likely to be followed.

In Chapter 3, six major industry problems, that have been noted by numerous analysts of construction, were identified; namely

- a fragmented industry structure
- a declining demand for its principal product: new housing
- a declining share of the GDP
- poor productivity
- cyclical activity and high unemployment
- an unwillingness to conduct research and development on its own behalf

Among these, we consider that low productivity, a declining market for new construction and, to some degree, cyclical activity are issues that can be addressed in part by introduction of new building practices and materials.

Among market forces external to the construction industry, the following have been identified by a number of industry analysts in recent reports [1,4,7-10]:

- a demand for repair and renovation of existing structures;
- a change in the nature of building needs away from low-rise residential towards so-called lifestyle buildings and institutional structures, both of which are expected to result from economic and demographic changes in Ontario;
- a demand from the sophisticated owner/investor and corporate tenants that rent commercial buildings for improved building performance over a range of categories;
- a desire by some more affluent house-buyers to enter more fully into the design process, with particular regard to energy efficiency, safety and comfort factors;
- a need to address the issue of the affordability of housing in urban areas.

Consideration of published information and discussions with trade associations, research organizations and other groups associated with the construction industry, have led us to group these trends under three general topics:

- mechanization and industrialization as a means to increase productivity in construction;
- repair, renovation and urban renewal as growth markets for construction;
- the role of the house buyer or renter, and the commercial owner or tenant in influencing changes in construction practice and technology.

MECHANIZATION AND INDUSTRIALIZATION OF CONSTRUCTION

At approximately 30% of total costs (excluding land), labour is a major component determining the profitability of construction, especially at the residential level. At the same time, the availability of labour, particularly skilled labour, is declining as craftsmen age and few young people are entering the industry. To this must be added the generally accepted view that productivity in construction is low relative to other goods producing industries in Canada. Together, these factors offer a strong inducement to the construction industry to improve profits by increasing productivity. Even if the construction industry fails to voluntarily increase productivity, the decline in demand for house construction may bring rationalization to the process. The CMHC report "The Changing Housing Industry in Canada: 1946–2001" predicts that substantial numbers of builders will leave the business over the next 12 years [9]. If this rationalization follows typical patterns for other industries, larger companies that place more emphasis on productivity and technology will gradually take over — as has largely been the case in engineering and commercial construction.

Historically, when the means have been available, industries have attempted to increase productivity by mechanization and automation of labour-intensive functions, usually by centralizing production in factories. There is no question that much of the technology exists to mechanize and industrialize a major portion of the construction process. It has been demonstrated on numerous occasions with respect to factory-made housing, in the production of mobile homes, and in the manufacture of prefabricated construction components available to builders. In general, the levels of factory fabrication envisioned by its early proponents have not materialized in North America to the extent that they have in some other countries, although less ambitious forms of industrialization have developed, the most important of which has been factory-production of building components and systems.

The impact of prefabricated components has differed between house construction and other types of building. To date, the routine use of factory-made components by the bulk of the house-building industry is largely limited to roof trusses and window units. In markets other than low-rise housing, some success has been found for modular concrete construction in the fabrication of hotels, dormitories and prisons. In commercial, public and institutional construction, prefabrication is more than a trend — it is becoming normal practice. We anticipate, as do other observers of the industry, that this process will continue, along with a slow development of industrialization in the housing sector where increased reliance on factory-produced products is expected [9].

In essence, what has been happening is that even without major developments in the production of complete buildings in factories, much of the labour that once was supplied at the job-site has either been mechanized at the site or removed to factory-based facilities. At the same time, encouragement has been given to the use of materials that cross the traditional boundaries of the building crafts, allowing for more extensive employment of unskilled labour and more productive construction.

We will see that a recurring theme in our consideration of opportunities and developments in building materials (Part II) has been the extent to which prefabrication and the production of building systems is entering the manufacturing of building products. Such industrialized features as panelized brick, precast concrete units and prefabricated window structures are now commonplace in the output of an increasingly sophisticated building products industry. The production of these systems will continue to demand new materials or better performance from old materials.

The challenge that the industrialization of construction presents to the industrial minerals sector is to secure its share of these new markets for specialized materials. If the demand is not met by the imaginative use of materials made from industrial minerals, then the metallurgical or chemical industries can be expected to provide alternative answers.

REPAIR, RENOVATION AND URBAN RECONSTRUCTION

In the period 1980–1988, the proportion of Canadian construction expenditure going to repair and renovation (as defined by Statistics Canada) has risen from $8-billion to a projected value of $12.6-billion. In 1988, ~16% of all construction was categorized as repair [11]. Rakhra [12] has shown that when consideration is given to total repair and renovation (including improvements and conversions), as much as 60% of all expenditure on residential construction falls into these categories. Defined this way, the value of residential renovation is expected to increase substantially in the next few years (Fig. 4-2). Projections recently developed by Clayton Associates [9] indicate that this trend will continue at least to the year 2000. Such a substantial proportion of construction expenditure must be expected to

Factory-built houses exhibited at the Japanese Building Centre, Tokyo. Photos courtesy of MATEX Consultants Inc.

influence the market for construction materials — if no more than to help sustain it in the face of a lower demand for new building. In addition, consideration of the nature of repair and renovation work suggests that it may introduce new opportunities for materials directly.

Maintaining and repairing existing building stock has always been a facet of the building industry. The fabric of buildings and infrastructure deteriorates in service and, unless it is maintained, a structure will ultimately become unusable. In the past, the trend was to replace old buildings that had deteriorated or were no longer suited to their original purpose. It appears, however, that more frequently, building owners are opting to renovate old structures to bring them up to contemporary standards of convenience and appearance, rather than to demolish and rebuild properties. This has led to an extensive demand for materials that can be used to replace, patch, cover or coat deteriorated building components.

Repair work on buildings can be divided into two segments: (i) general maintenance to offset the results of normal deterioration and use; and (ii) repair of damage caused by failure of materials to meet normal service requirements. Much of the first type of repair is done by the home- or building-owner on a piece-meal basis. It is the core of the do-it-yourself market and the bulk of work for many small contractors. Far more serious is the need to repair structures that have failed because they either were not designed to withstand service conditions, or were not properly constructed, due to poor workmanship. Notorious in this respect are the vast numbers of apartment and office parking garages that have been severely damaged by road salt.

Renovation can take two forms — private or public. In private renovation, the emphasis is on upgrading the quality of existing structures, whereas in public renovation, the emphasis may be on preservation of structure and appearance.

Property costs have made home-ownership in some cities possible only for two groups: older people whose properties were purchased when prices were much lower relative to earnings, and the wealthy. Consequently, as the population ages (see below), properties in older, established neighbourhoods are being renovated and converted to meet the lifestyle demands of new, wealthier owners. This has been a common feature in cities throughout the world and has been dubbed "gentrification" to reflect the marked differences in economic circumstances of the old and the new inhabitants of neighbourhoods that experience renovation.

A factor influencing the trend to renovation has come from a new public awareness of the "value" of cultural heritage. Once city planners chose to tear down and replace

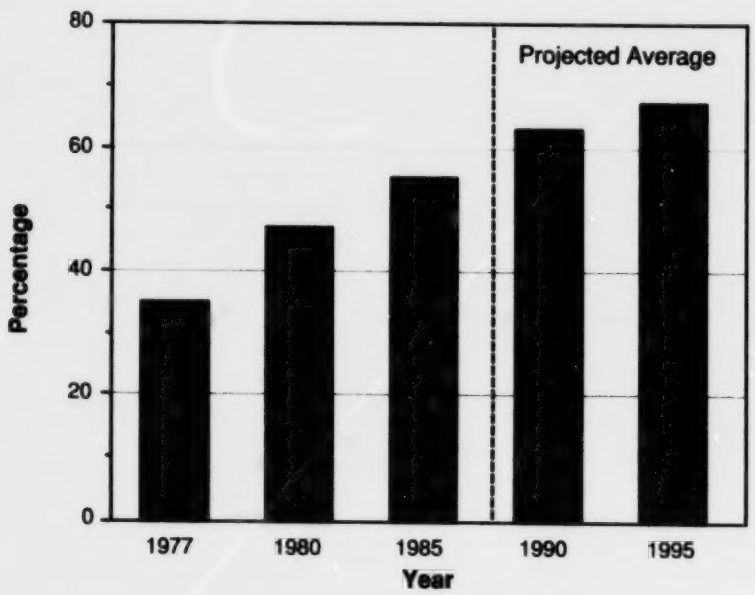

Figure 4-2 **Value of residential renovation as a percentage of total residential construction. Source: ref. (15).**

older structures; now, on each occasion when this is advocated, local residents seek to preserve rather than redevelop these sites. In response to this pressure, governments have been spending publec money on heritage projects, and private developers have hone to great lengths to incorporate the "old" with the "new." Some remarkable examples of this are to be seen in the new ALCAN head office in Montreal and at Harbourfront in Toronto. There would appear to be no major reasons why this trend will not continue into the future. Indeed, the popularity of such "people places" as The Heritage Properties in Halifax, Toronto's Harbourfront and the Granville Island development in Vancouver would suggest that this trend will grow.

The requirements of the repair market and, to a much larger degree, those of renovation, open up a number of market opportunities for building products. The largest opportunity in repair work, for both the construction industry and its suppliers, is in the refurbishment of civil structures. The most needed work is the repair and replacement of infrastructure in older cities—notably, highways, overpasses, railway structures, and waste-water systems. Although these aspects of engineering construction are not in the purview of this report, we recommend that the industrial mineral sector look intently at this market as a potential consumer of industrial minerals.

Within the area of building repair and renovation, as distinct from civil works, materials opportunities appear to lie in the manufacture of "look-alike" products:

- Older buildings have aesthetic appeal, in part generatedby their "oldness." Weathered brick or stone, when they are not deteriorated, have a distinctive character that is hard to match with new mass-produced materials. A market thus exists for providing materials with a "matching look," especially for the large, publicly-funded renovation projects.

Typical damage to parking garage structures by use of deicing salt in the winter.

- In a related way, the form and dimensions of building units may have changed over time. An example is that of clay brick. Many older buildings were made using hand-formed bricks that are not the same size or colour, and do not have the sharp features of modern, machine-made brick.
- Stone, wrought-iron and hardwood were once the media for craftsmen to produce decorations for buildings. Ontario's farm houses are famous for their "gingerbread" wooden decoration, and many of our public buildings display carved stone or terra-cotta facia ornaments. Drainpipes, fences and roof ornaments of wrought-iron are essential parts of the heritage appearance of many buildings.

The markets for these types of items are fragmented, specialized, local and often require small volumes. All of these factors deter the large building materials manufacturers from producing them. However, they are major opportunities to an entrepreneurial minerals producer willing to enter the manufacture of value-added custom made products.

In addition to "look-alike" products that address aesthetics, opportunities are to be found in the need to upgrade the safety and convenience of buildings when they are renovated. The following examples illustrate some aspects of this market:

- Many buildings contain asbestos that should be removed and replaced with other insulation products (see Chapter 14.) Other buildings may have inadequate insulation, requiring upgrading as an energy-saving option.
- In Britain, where much of the older housing stock does not meet modern fire codes, flooring must be upgraded when renovation is done to convert single-family to multiple-family dwellings. One company [13] has met this need with a gypsum flooring system specifically designed for retrofit installation in old houses. (See Chapter 8).

Meeting these opportunities is likely to be attractive to existing producers of building materials. The challenges here lie in adapting existing product lines to renovation market needs — as has been the case with the gypsum flooring system noted above. It is impossible to illustrate all of the opportunities presented by repair and renovation, although numerous examples of specific applications are discussed in the next chapter in relation to the role of different building product types.

In addition to the renovation of neighbourhoods in urban centres, other significant changes are underway in the manner in which cities are seen to serve the population. At one time, when many of the major centres in the province were established, railways, ports and industry were located in the city core. They provided the reason for the city's existence and were the principal source of employment. The nature of work in the largest of Ontario's cities has changed — industrial activity, railways and port facilities have declined in importance, while service and financial employment have grown rapidly. Between 1980 and 1987, the proportion of Canadian workers in the service sector rose from under 66% to almost 70% [14].

Service employment is in public or welfare, business and financial, or consumer functions. These activities require different types of buildings from the older types of employment. Thus, industrial and railway lands are being redeveloped to provide office, commercial, public and luxury housing. The consequent trend is to construct high-rise office and apartment buildings, along with major public buildings, such as the Skydome and the proposed Opera House in Toronto, and the National Art Gallery in Ottawa.

The large-scale urban renewal under way in the larger cities does not offer any particular new opportunities to the producer of building products. Rather, it is a part of the general level of new construction on-going in the province. However, because most of the construction is of "prestige" buildings, opportunities will exist for the supply of the types of products most used in such architect-designed structures. In particular, unless tastes change, we can expect to see much more stone, glass and aluminum on the exterior of buildings supported by high-strength concrete and steel. More decorative materials will be required both inside and outside the buildings, and some development of so-called high-technology structures can be anticipated.

As development continues, the necessity to build in confined spaces is expected to affect building in the inner core of the cities. This may be experienced as the need for more of what has been termed "urban infill" architecture, in which case a demand for materials suitable to match existing structures may be experienced — similar to that from renovation work. Other effects of inner-city needs will be the use of prefabricated units that can be moved into confined spaces and the use of high-strength and lightweight concretes for the exceptionally tall structures that will be built to maximize land use (see Chapter 10).

CONSUMER NEEDS AND THE CONSTRUCTION MARKET

The trend towards industrialization will be driven by the need to improve productivity in the construction industry. Trends in repair, renovation and urban renewal are driven by other economic changes in the ways that urban areas will function. The third trend that the authors consider likely to influence changes in building practice comes from a different direction — the growing role of consumers in determining the nature and quality of the buildings in which they work and live. The trend has been noted by numerous industry observers as exhibiting a number of facets: the desire for "lifestyle" housing; a greater emphasis on quality, distinctiveness and value in buildings; a demand for better durability and performance, and easier maintenance; and, most importantly, a demand for improved attention to the health, safety and productivity of building occupants. Another form of consumer influence, perhaps expressed through a political forum rather than by individual consumer choice in the market-place, is the need for affordable housing. As the demand for construction declines in the housing sector, and the market moves towards favouring buyers over builders, companies in the industry can be expected to seek a competitive edge by addressing these issues.

For the purposes of this report, we have chosen to group these market-driven factors under the general concept of "consumerism," largely because the interests that are expressed are those of the consumer, tenant or owner, rather than the producer of buildings. In this context, there are different types of consumers for different types of buildings. In housing, the largest group of consumers are the resident homeowners. In 1986, ~62% of all Canadian households were owner-occupied [12]; tenants of rental properties form the remaining group, within which both building owners and tenants are the consumers — though with different interests. As was noted earlier in this chapter, the industry experience to date has been one of minimal participation by homeowners in choosing the way in which buildings are produced. Some observers of the real estate market consider that this situation is undergoing changes, with buyers being more knowledgable and selective [7,10].

In commercial buildings, the consumers are:

- the building owners, whose interests lie in maximizing return on investment while minimizing maintenance costs;
- corporate tenants, whose interests lie in the contribution that the building makes to the productivity of their businesses;
- the employees of corporate tenants, whose interests lie in comfort and convenience — in having a pleasing and healthy place in which to work.

Similar distributions of interest are seen in public, institutional and industrial buildings. In these groups, the owner has always been a participant in the selection of materials, particularly those that affect appearance and rentability of the building. Now, there is evidence that other factors are becoming important, particularly in relation to durability, and matters where owner liability for hazards to occupants are at issue [15].

It seems possible to conclude, then, from the needs and changing desires of all these groups, that from the perspective of building materials, the impact of "consumerism" will be most strongly experienced in six areas:

- appropriateness to lifestyle
- aesthetics
- durability and maintenance
- health and safety
- convenience and comfort
- affordability

The relative importance of these issues may differ from one building type to another, and from one consumer group to another.

Lifestyle

As a recent CMHC report notes, while demand for new housing will continue to decline through the 1990s, new types of house buyers are emerging [9]. These are older people, active seniors and "empty-nesters." They will want to buy into residential environments that are different from

the traditional single-family home. As the population ages these groups will become more prominent in determining the character of the housing market.

At the present time, about 10% of all Canadians are 65 years of age or older; by the end of the century this will have reached 13%, and by the year 2031 the proportion will have increased to 25% [16]. Among the elderly, in 1986, 45,300 men (12%) and 120,000 women (19%) lived in institutions. Statistics Canada projections suggest that by the year 2001, 75,000 men (12%) and 242,500 women (23%) will require such accommodation [17]. Others will seek different forms of living styles for their retirement; some of these possible forms, ranging from accessory apartments that will involve renovation to existing homes, to mobile homes that will be built in factories, have been reviewed by CMHC [16]. Clearly, the impact of the needs of the older consumer of housing is going to affect the nature of buildings, the ways in which they are built and the location of new development.

Aesthetics

The concepts defining aesthetics depend greatly upon the purpose of the building. In housing, the current desire is to have a traditional house — not too different from the market norm (to maintain resale potential), but distinctive in appearance. In commercial property, especially the prestigious office buildings of the downtown core, the emphasis, though conservative overall, can permit bold statements of style and non-traditional use of materials. Industrial and institutional structures are more likely to emphasize function over aesthetics.

From a materials perspective, therefore, single-family housing, from affordable to the upper end of the market, is likely to favour use of traditional materials — namely wood, stone and masonry. Housing for an aging population may extend from the traditional forms to mobile homes, thereby spanning the range of materials. Commercial city construction offers the broad run of materials — steel, concrete, aluminum, stone, glass and masonry — with much of the present emphasis on stone, glass and aluminum, in visible areas, and concrete for structural members. The role of aesthetics as a factor in materials selection in prestige construction should not be underestimated. Among the factors considered when the Scotia Plaza in Toronto was being designed was the desire for a "fresh image," different from the surrounding bank towers. The owners wanted a warm, rich and distinct colour with a red tone for the tower. Napoleon red granites were considered from a number of potential sources, with final selection going to material from Sweden [3].

From the perspective of the supplier of industrial minerals, the desire for aesthetics in buildings will have little direct influence except to sustain the market for traditional materials. If some of the new materials can be marketed for their high-technology appeal, then these may offer other opportunities discussed elsewhere in the report.

Durability and Maintenance

Whatever the material of choice — both from an investment point of view and to sustain the aesthetic

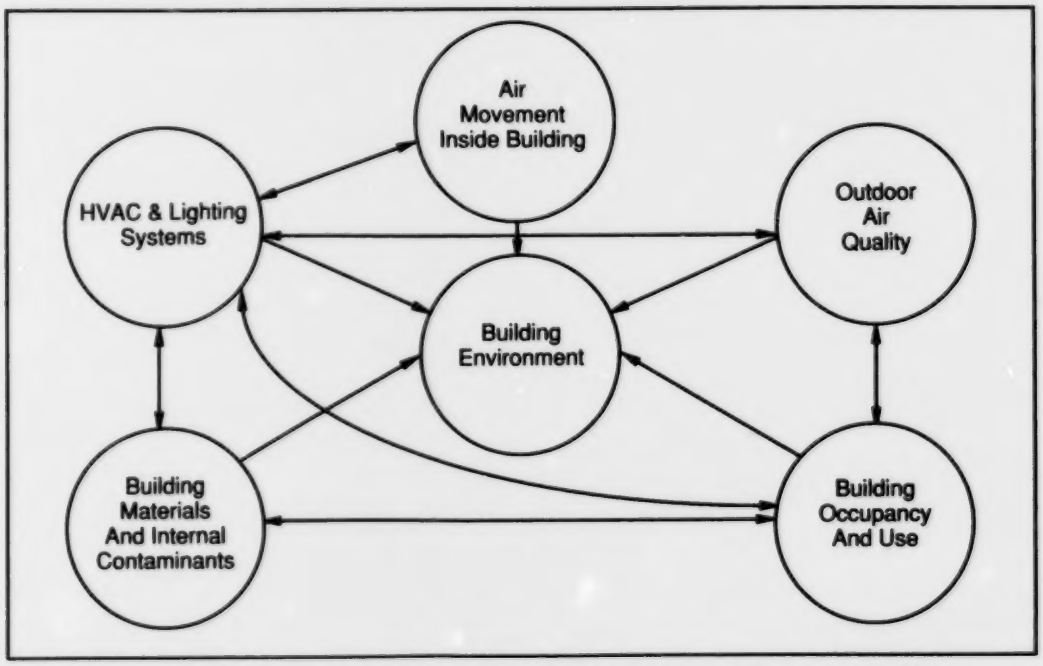

Figure 4-3 **Factors which interact in the indoor building environment. Source: ref. (18).**

component — durability is a major factor in construction. Owners of office and apartment buildings have faced exceptional costs in the past few years for the repair and replacement of parking facilities; this has made them conscious of life-time costs in construction investment. At the same time, most home owners conduct their own repairs and maintenance: as the price of housing rises, they expect to see better performance in materials and components, especially windows and roofs.

It has been claimed that during the life of a typical office building, operating and maintenance costs can total 700% of the original building cost [5]. During that same lifetime, for most office buildings and some homes, many changes in occupancy and use will have occurred. While the building shell may have a life span of 50 years, the mechanical and electrical fittings are designed to last 15 years, and the decorative fittings 3–5 years; the interior environment may change from month to month. The materials used must be consistent with durability, ease of maintenance and flexibility of function in the building.

Health and Safety

Throughout the developed world, an increasingly informed population is becoming aware of numerous hazards in the daily environment. Much of the focus has been on the external environment — with such as issues as the pollution of air, water and soil by industry and waste disposal. However, as people have become more sensitive to the quality of their surroundings, a new focus has been placed on the interior environment, at home and at work. As a consequence, a new emphasis has been placed on the effects that some building materials may have on human health and comfort. Not all of the issues that have been raised have related to real hazards, and in some cases actions have been taken that have been unnecessary. However, some materials do have the potential to irritate building occupants, and others may be truly hazardous to health, while yet others become hazardous in a fire. Continuing pressure is being maintained in North America to eradicate these hazards. It should be expected that such issues will continue to be passed on to the construction industry in the form of pressure from building owners, occupiers and regulators for the use of non-hazardous materials in construction. As a consequence, we expect to see an increase in demand for:

- improvements in the quality of indoor air;
- the substitution of innocuous materials for toxic or irritant substances in buildings;
- improved fire safety, particularly with respect to smoke and fume hazards.

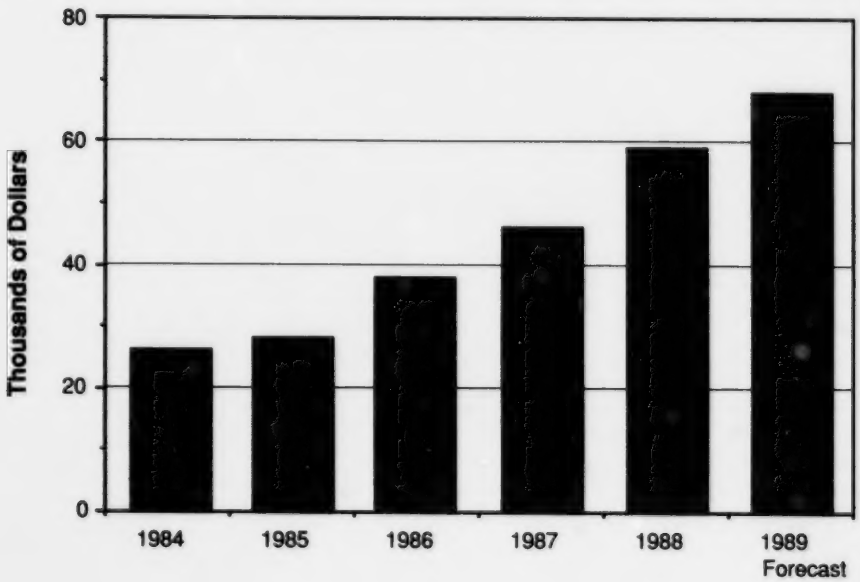

Figure 4-4 **Required income for average MLS condominium townhouse. Source: ref. (20).**

Sustaining a healthy building is not solely a matter of materials selection. As the "Healthy Building Manual," published by Energy, Mines and Resources Canada, notes, a complex interaction of factors is involved (Fig. 4-3) with materials and contaminants playing a role [18].

In addition to directly or potentially hazardous materials, ventilation in some buildings is inadequate; conditions can arise in which non-hazardous, but objectionable, odours circulate within the indoor air. This leads to a poor indoor-air quality, and in extreme cases to what has become known as the "sick building syndrome." In sick buildings, especially offices, occupants complain of headaches, nausea and general malaise. Air-quality tests usually detect no hazard, but the complaints continue, often with increasing absenteeism among employees. In extreme cases, a building can kill — Legionnaire's Disease, as it is called, has been directly attributed to problems with air circulation systems in hotels and hospitals [19].

Supplying the building industry with replacement materials — new materials or building systems that remove or prevent "sick buildings" and hazards to health — is expected to provide a growing opportunity to the building materials industry. In general, with the notable exception of asbestos, the industrial mineral-based materials that are used in buildings have been largely free from consideration as potential sources of hazardous conditions. The polymer-based materials used in plastic surfaces, coatings and sealants have been much more suspect, a factor that has played some considerable part in their rather slow acceptance in some construction applications. Two examples that serve to illustrate the problems that can be experienced when construction materials are suspected of being unsafe or hazardous — urea-formaldehyde foam-insulation (UFFI) and asbestos — are discussed in Chapters 13 and 14, respectively.

One current commentator on the legal and liability aspects of "sick buildings" notes: "As the general public become more aware of the building pollution problem, and as more is learned about it, it is reasonable to assume that the number of claims brought against owners, builders, materials suppliers and designers for real or perceived illness will increase [15]." Obviously, concern over liability is a major factor in selecting building materials.

Convenience and Comfort

A building may be described as "convenient" from a consumer perspective if it is designed to meet its end-use requirements, needs little maintenance and is easy and inexpensive to manage. "Comfort" is a more general issue, and certainly has many elements in common with health and safety. The elements of comfort require that the building temperature and humidity can be maintained at a normal level, noise and associated factors such as reverberation of sound are minimized, and an adequate and pleasing level of lighting can be sustained. Both issues confront the demand for the building to perform as a system, capable of sustaining a stable, healthy indoor environment.

In domestic construction, comfort and convenience are largely fashion issues. In commercial construction they are increasingly being seen as major factors in the rentability of buildings. This subject is too complex to be discussed in this report; however, it is sufficient to note that the influence of a building on the efficiency and work performance of those who are employed to work in it is considerable and has been recognized by building owners and tenants alike as a major factor in rentability [6]. Many of these factors relate to building design, while others have an impact on the selection of materials in the following ways:

- Rough textured surfaces, made of soft materials, are tedious and expensive to keep clean, and require more time for maintenance.
- Rigid highly polished surfaces, unless combined with soft sound-absorbent furnishings, can induce distracting reverberations.
- Some materials act as passive thermal storage devices and help maintain stable temperatures.
- Glass as a building skin must be made part of the total thermal control system if temperature variations are to be minimized.
- Some materials are needed to provide shielding for electronic equipment.
- Building walls and floors must be designed for easy access to cable systems — precast flooring has a particular role to play in this regard.
- The use of atrium structures can increase the access of natural light to the building.
- For areas that cannot have direct access to windows, natural light can be "piped" to the interior of buildings by the use of plastic-coated light ducts.

Affordability

Access to home ownership is becoming increasingly difficult for first-time buyers in major centres across the province. In December 1987, the average MLS condominium townhouse sold for nearly $136,500 in Toronto. To obtain an 80% mortgage at 10.75% interest, an annual family income of $46,000 was required for 30% of income to be allocated to principal, interest and taxes. By the end of 1989, the same house is expected to cost $199,000, with mortgage rates at 11.75%, and a family income of $69,000 required for the same purchase [20]. Figure 4-4 shows required income versus MLS prices for this type of property over the period 1984–1989. The severe increase in income requirement is part of what has been termed the crisis in affordable housing. At the same time, the number of renters in need increased by 27.4% between 1982 and 1985. The largest increase was in the area of affordability, followed by adequacy and suitability of accommodation [21].

Clearly, much of this problem is generated by lack of supply and inflation of land prices rather than the cost of construction. Thus, the role played by materials costs is probably small. Affordability of housing, however, is a social problem that will ultimately require a political solution. When that solution is found, it is likely that reducing the costs of construction for housing at the entry level will be a component. Within that component, both materials costs and the cost of labour to construct will need to be considered. One option that may be evaluated is to use factory construction as a means to reduce cost. If this is the case, major opportunities would arise for suppliers to provide suitable materials on a significant scale, and, in the context of opportunities for construction materials, such a possibility cannot be ignored. The issues surrounding the current technology of factory construction from the perspectives of the materials producers will be returned to in Part II of the report.

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5. Building Products in Ontario

Except for aggregates, construction materials fall under the category of *manufactured* products, most of which derive from four industry sectors:

- Forest products
- Metals fabrication
- Chemical products
- Industrial minerals

Overall, the building products that come from the forest products, metals and chemical products sectors are a major source of competition for the industrial minerals sector, although, in a few cases, industrial minerals may also be sold into these industries as process chemicals or raw materials: notable examples would be the use of lime by the steel industry and the use of mineral fillers by the plastics sector of the chemicals industry.

In published statistical compilations [1-3], the building products manufacturing industry is usually presented in terms of numerous establishments, most of which are relatively specialized in their product lines, but many of which also manufacture products not used in building at all. A useful overview of the structure of the Canadian building products manufacturing industry can be obtained from the Statistics Canada data for 1982 and 1983, compiled by Clayton Research Associates (Table 5-1). The corresponding distribution of company size (in terms of number of employees) for the firms reporting more than 30% of production in the building materials category is given in Table 5-2. The following general picture of the industry emerges from these data:

- In 1983, some 5,433 establishments produced ~$22-billion, of which 31% ($6.7-billion) was estimated to be building products.
- Building products are manufactured both by industries that specialize in the construction market and by companies that produce other items or goods. Some of the firms produce only minor quantities of building products as a part of their manufacturing operations. For example, the following manufacturing industries ship relatively little to the construction industry: primary steel (4%), machinery (4%), abrasives (6%), boiler making (3%) and rolled, cast or extruded non-ferrous metals (3%). Others are largely committed to the construction market: e.g. asphalt shingles (100%), hydraulic cement (100%), and paint and varnish (100%).
- The industry is composed principally (~85%) of small- to medium-sized establishments with less than 50 workers. It is dominated by metal fabrication operations (53%) and wood products manufacturers (23%). Industrial minerals accounted for the major output of ~500 establishments (15.8%), the majority of which were in the concrete products and ready-mixed concrete businesses.

TABLE 5 - 1 PROFILES OF FIRMS IN THE BUILDING PRODUCTS MANUFACTURING INDUSTRY (ONTARIO 1982 AND 1983 DATA)

1980 SIC Code	Type of Manufacturer	Number of Establishments 1982	1983	Value of Goods Shipped 1982 ($-millions)	Building Products (est.) %	Value ($-millions)	
251	Sawmill, planing and shingles	na	228	452	79	357	
252	Veneer and plywood	21	23	99	94	93	
254	Sash, door and other millwork	339	375	396	99	392	
259	Other wood	na	97	185	90	166	
272	Asphalt roofing	5	5	96	100	96	
291	Primary steel	na	25	4,692	4	188	
292	Steel pipe and tube	na	16	469	32	150	
294	Iron foundaries	na	59	363	17	62	
296	Aluminum rolling, casting and extruding	na	37	502	20	100	
297	Copper and copper alloy rolling, casting and extruding	na	29	na	11	na	
299	Other rolled, cast and extruded non-ferrous metal products	na	51	na	3	na	
301	Power boiler and heat exch.	27	24	590	3	18	
302	Fabricated structural metals	na	159	426	85	362	
303	Ornamental and architectural	na	310	552	99	546	
304	Stamped, pressed and coated metal products	450	479	1,787	16	286	
305	Wire and wire products	187	189	787	36	283	
306	Hardware, tool and cutlery	na	634	736	32	236	
307	Heating equipment	na	74	219	60	131	
308	Machine shop	546	591	272	12	33	
309	Other metal fabricating	na	302	1,042	57	594	
311-319	Machinery		806	858	3,887	4	155
332	Major appliance	na	19	526	21	110	
333	Electric lighting	na	74	135	83	112	
338	Communications and energy wire and cable		na	29	610	54	329
339	Other electrical products	na	69	676	44	297	
351	Clay products	na	57	85	76	65	
352	Hydraulic cement	7	7	188	100	188	
354	Concrete products	na	182	228	81	185	
355	Ready-mix concrete	150	163	287	98	281	
356	Glass and glass products	73	75	576	15	86	
357	Abrasives	21	22	152	6	9	
358	Lime	6	6	70	100	70	
359	Other non-met. mineral products	80	86	320	77	247	
375	Paint and varnish	na	79	482	100	482	
Total building products manufacturing industry		na	5,433	21,887	31	6,709	

Source: Clayton Research Associates, based on Statistics Canada Census of Manufacturers, ref. [1]

TABLE 5-2 DISTRIBUTION OF ESTABLISHMENT SIZE AMONG PRODUCERS OF DIFFERENT BUILDING PRODUCTS

SIC	Product category	Number of Establishments Employing							
		1–9	10–19	20–49	50–99	100–199	200–500	500–1000	Totals
251		124	33	30	23	14	4	0	228
252	Wood	2	1	7	4	8	1	0	23
254		210	74	61	18	10	2	0	375
259		59	13	10	6	8	1	0	97
272	Asphalt	0	0	0	4	1	0	0	5
292	Steel	2	0	4	4	1	4	1	16
302		48	39	45	15	6	5	1	159
303		162	65	49	26	6	2	0	310
305	Fabricated	60	37	44	27	16	5	0	189
306	metals	365	126	86	34	20	3	0	634
307		24	20	14	11	3	1	1	74
309		120	56	69	33	17	6	1	302
333		22	17	17	12	4	1	1	74
338	Electrical	2	3	2	6	10	5	1	29
339		18	13	13	6	8	11	0	69
351		35	7	3	8	4	0	0	57
352		0	0	0	2	3	2	0	7
354	Industrial	88	44	38	7	5	0	0	182
355	minerals	88	52	14	5	4	0	0	163
358		0	0	1	4	1	0	0	6
359		38	14	12	10	7	4	1	86
375	Paint	27	12	19	10	7	4	0	79
Totals		1494	626	538	275	163	61	7	3,164
%		47.2	19.8	17.0	8.7	5.2	1.9	0.2	100.0

Percent to industrial minerals 15.8

Source: Clayton Research Associates, based on Statistics Canada Census of Manufacturers, ref. [1].

- A wide variety of materials are involved in the manufacture of building products, including wood, asphalt, metals, glass, structural materials, non-metallic minerals and paints. Notably absent from this compilation are the plastic manufacturing companies that produce building products. Discussion of this extremely diverse segment of the industry is included in Chapter 13.
- Nationally, the majority of building products shipments are from the forest products sector (principally lumber) with fabricated metals and non-metallic minerals in second and third places, respectively. In Ontario, forest products play a relatively minor role in shipments, fabricated metals and non-metallic minerals being the dominant product types (Fig. 5-1).

Considered superficially, the statistical data would indicate that the building products manufacturing industry is extremely fragmented with numerous sub-divisions and small establishments. However, what is not clear from the statistical compilations is the level to which many of the companies and establishments are divisions and subsidiaries of large, often multi-national, corporations. For example, of the 345 establishments recorded in Table 5-1 under SIC 354 (concrete products) and SIC 355 (ready-mix concrete), a large proportion report to both categories, and a substantial group are subsidiaries or divisions of the four major cement manufacturers in Ontario. This issue is considered in more detail in relation to different segments of the industry in Part II of the report.

In the forest products and metals fabrication sectors, the level of integration is not so evident, there being many small fabrication operations that directly supply the construction industry, along with a few large producers and manufacturers of prefabricated building products (e.g. windows, siding and building systems). In the chemical sector, some product types, notably insulation and concrete chemicals, are dominated by the international chemicals-producing companies; however, in much of the plastics fabrication area, small operations remain which serve the construction industry directly.

Building products can be disaggregated into three groups: crude products or raw products subjected only to preliminary processing (e.g. logs and stone); fabricated products that have undergone some level of processing (e.g. cement, lumber, wire and bricks); and end-products, such as furnaces, sinks and sanitary ware. The level of value added in manufacturing building products that use industrial minerals covers a broad range. At one extreme are the producers of aggregates and dimension stone that ship largely unprocessed materials to concrete manufacturers or masonry contractors. Other companies produce building materials in a more vertically integrated manner — the cement manufacturers are producers of both raw minerals (limestone, clay and shale) and manufactured goods (cement and concrete); and, similarly, the gypsum companies operate mines, produce plaster and manufacture wallboard. At the highest value-added extreme, chemical companies produce or purchase resins, compound them and mould finished products.

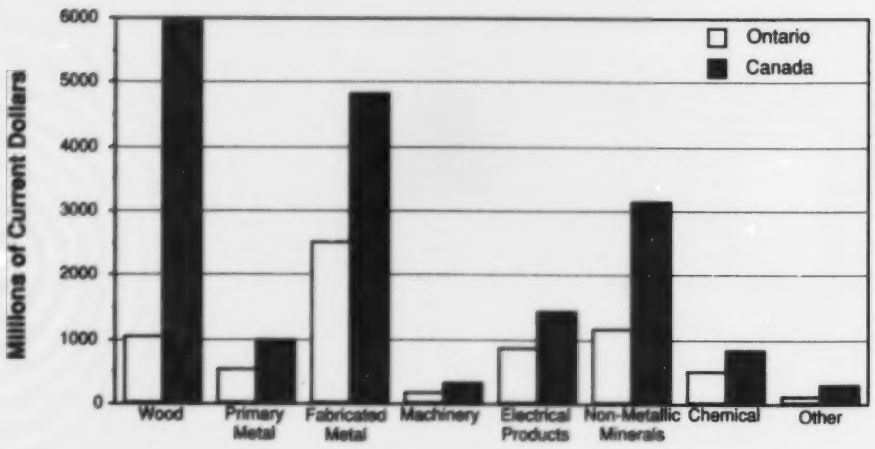

Figure 5-1 **Estimated value of shipments of building products by type of manufacturer, Ontario and Canada, 1982. Source: ref. (2)**

The building products industry in Ontario, in addition to supplying local construction needs, exports a considerable proportion of its production. The value of exports of building products has been increasing over the past decade, both from Ontario and from Canada generally (Fig. 5-2). The provincial trade in building products was, on average, almost in balance in the period 1981-1985, with ~$2.8-billion of both imports and exports. This was an improvement over the previous five-year period when a substantial trade deficit existed in the same product group. The value of Ontario exports of building products has been increasing at a much greater rate than for the nation as a whole, with most of the increase in provincial exports coming from semi-finished products (Figs. 5-3 and 5-4).

Figure 5-5 shows data for exported building materials, in terms of the degree of processing or added value, for the periods 1976–1980 and 1981–1985 [2]. These data show that, compared with the rest of Canada, Ontario accounts for most of the end-products shipped for export and that most of the products shipped from the province are in this category. This is interpreted as showing a considerable degree of value-added activity in the Ontario building products industry. However, most of the fabricated building products exported from the province were in the lumber or metal products groups, neither of which incorporate much of the output from the industrial minerals sector. Products that do consume goods from this sector (such as cement, lime, and wallboard) are to be found in the "Other" category in Fig. 5-4. Ontario accounts for almost half of the Canadian exports to the U.S. of products so categorized.

The United States is by far the most important export market for building products both from Ontario and from Canada. A very clear relationship exists between the real value of exports of building products from Ontario and Canada to the U.S.A. and the level of U.S. building construction expenditures (Fig. 5-2). The markets in the U.S. for Ontario building products appear to be regionally located in the Midwestern and Northeastern States. This is not surprising given the relatively low-value and high transport costs of many building products.

On the import side, the Ontario Building Industry Development Board indicated that a substitution of 50% by Ontario-made products would result in the creation of an extra 40,000 jobs, $60-million in provincial revenue and $1-billion of annual output [3]. Details of the import categories and their approximate values identified by the Board are shown in Table 5-3.

In terms of added value, the building products coming into Ontario are heavily weighted towards end-products (Figs. 5-6 and 5-7). These comprised about 46% of building products imported in 1981–1985; the comparable share for exports was 24%.

As is evident from this brief overview, the manufacturing of building products involves industrial minerals in a complex interaction of material recovery and manufacturing operations dealing with a diversity of material types. The broad range of industries that produce building products from industrial minerals are examined further in Part II of this report.

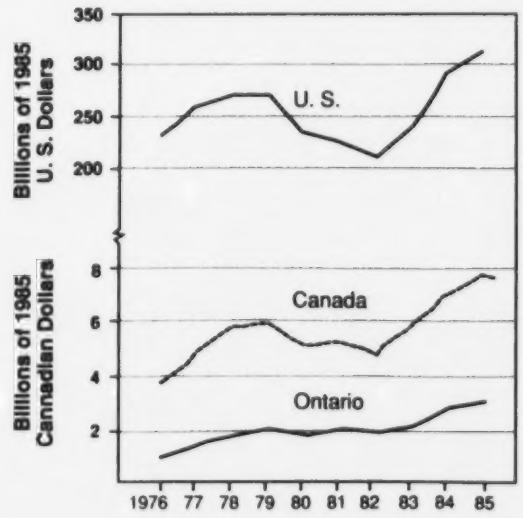

Figure 5-2. Real value of exports of building products from Ontario and Canada to the United States, compared with real building construction expenditures in the United States, 1976–1985. Source: ref. (2).

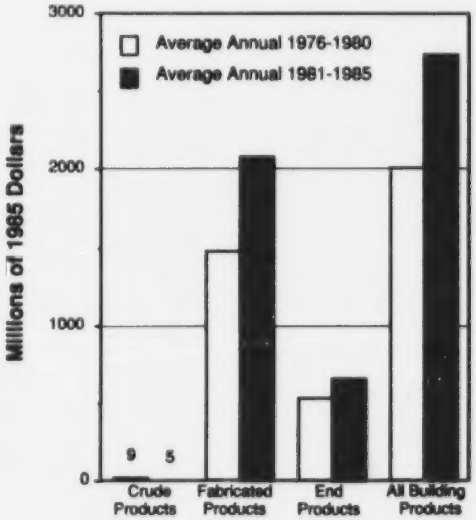

Figure 5-3. Real value of domestic exports by degree of processing, Ontario 1976–1985. Source: ref. (2).

In general, although, as was seen in Chapters 3 and 4, the ways in which construction is conducted and the details of building technology are changing, the vast majority of building materials that involve industrial minerals draw their raw materials from the same mineral groups that have been used since ancient times. For this reason, and because the focus of this report is on the interests of the industrial minerals sector, we have chosen to examine the individual segments of the building products industry in terms of the basic minerals or primary products used in their manufacture, rather than, as is more common practice, in relation to structural or functional elements in buildings. An example in point would be clay products — which are used in flooring, roofing, cladding and drainage — and their competition in each of these categories with materials made from other minerals, such as glass, concrete, stone, plastics, etc. The common theme of mineral origin has been taken as the organizing basis for Part II of the report which examines

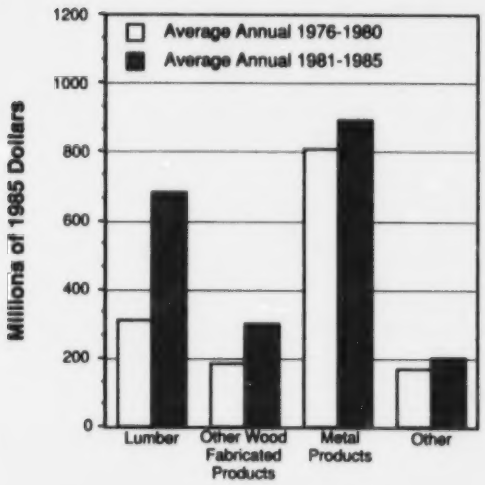

Figure 5-4. Real value of domestic exports of fabricated building products by type of commodity, Ontario 1976–1985. Source: ref. (2).

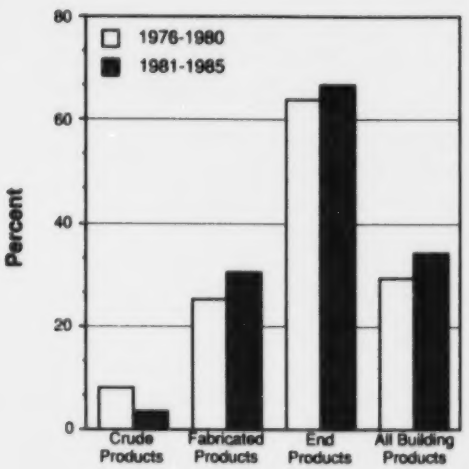

Figure 5-5. Domestic exports by degree of processing, Ontario as percent of Canada 1976-85. Source: ref. (2).

TABLE 5-3 APPROXIMATE VALUE OF BUILDING MATERIALS IMPORTED INTO ONTARIO

Category	Approximate Value ($M per year)
Electrical fixtures	563
Metal valves and pipe fittings	408
Nails, screws and hardware	395
Metal piping and tubing	388
Heating, air conditioning products	313
Lumber	286
Construction metal	160
Glass products	131
Plywood and particle board	115
Building bricks and blocks	112

Source: ref. [3]

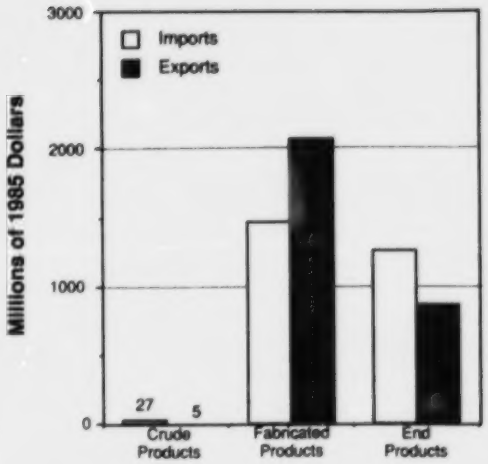

Figure 5-6. Average annual real value of imports and domestic exports of building products by degree of processing, Ontario 1981–1985. Source: ref. (2).

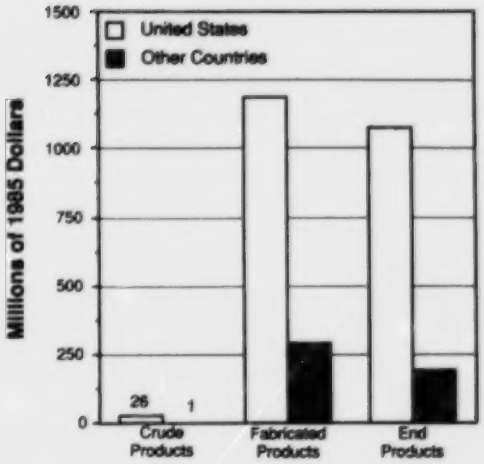

Figure 5-7. Average real value of imports of building products by degree of processing and country, Ontario 1981–1985. Source: ref. (2).

opportunities for minerals in the following key industrial groups:

- Stone and mineral aggregates
- Glass building products
- Lime products
- Polymer-based building products and mineral fillers
- Gypsum products
- Hydraulic cements
- Alternatives to asbestos
- Concrete and cement-based products
- New materials
- Clay building products

Product groups coming from the other industry sectors are discussed further in Part III of the report in relation to the extent to which they compete with industrial minerals.

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2. The Building Industry Strategy Board, "Building Tomorrow — Ontario Building Industry Highlights," (Ontario Ministry of Housing, Oct. 1986).
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Part II Building Materials: Status and Opportunities for Industrial Minerals

6. Stone and Mineral Aggregates

- Marble
- Granite
- Sandstone
- Dolostone
- Limestone
- Gneiss
- (Perlite)
- (Vermiculite)
- (Clays)

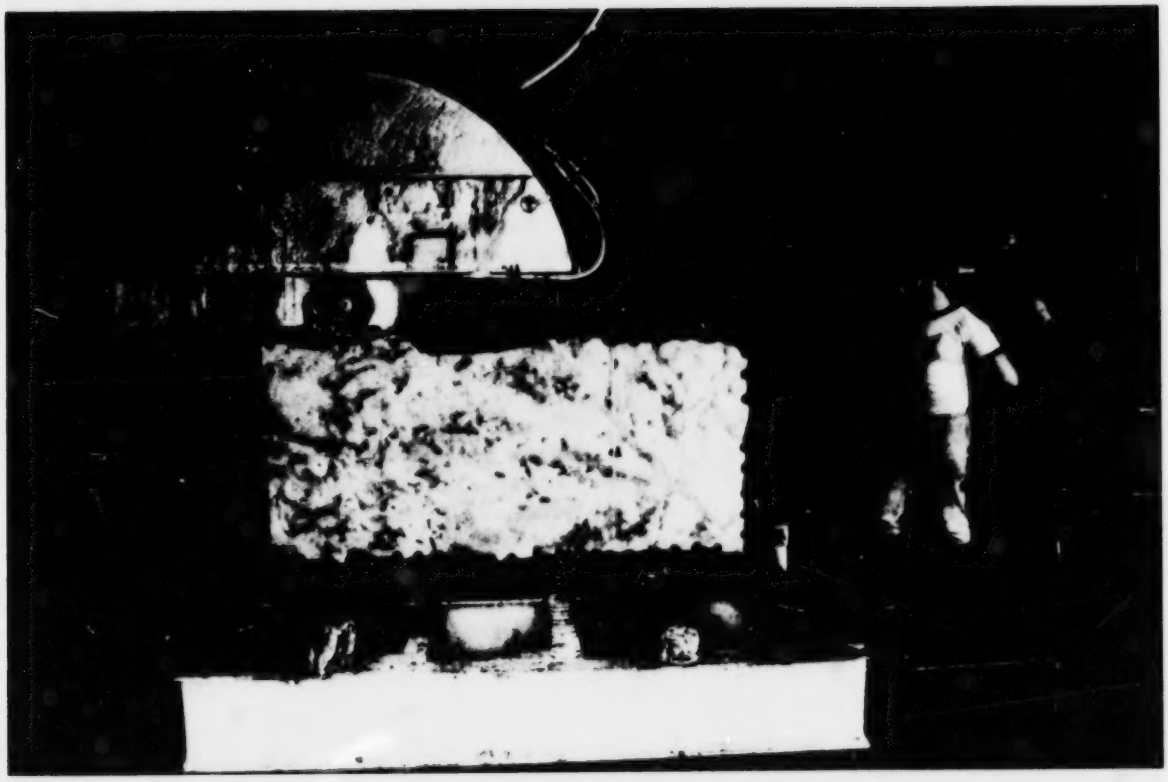
Because it is durable and readily available, stone in one form or another has been an important construction material from earliest times. Modern construction uses cut natural stone for the structural fabric and decoration of buildings, while sand, gravel, and crushed quarried stone are used as aggregates in composite materials such as concrete. Civil construction makes major use of natural aggregates and crushed stone in foundations for sewers, highways and railroads.

Internationally, the great ages of stone construction have reflected the wealth of societies. Stone has been particularly associated with an image of solidity and permanence in construction. As new materials and techniques have been developed, builders have constantly returned to stone for special use as a structural or decorative material. Buildings such as banks, office towers and public structures thus frequently employ stone for aesthetic purposes. New technologies have enabled the development of novel stone products such as sawn slabs of the hardest non-foliated rock, formed artificial stone, and moulded products of terrazzo, pozzolan, cement or concrete type materials. These have permitted designers to retain the aesthetic qualities of stone while benefiting from the advantages of modern construction technology.

Some of the great stone quarries of the world, that have provided building materials for centuries, are still in operation today. The marbles of Carrara and the slates of Angers, both famous through centuries of stone construction, are still in the forefront of production technologies and in the development of new products or uses for stone. Most of these developments have been directed to popularizing and broadening the use of stone; others have led to increased production and productivity, reduced wastage and more efficient extraction and dressing. As we will see, the ancient art of stone finishing has seen much of its recent renaissance as a result of mechanization and industrialization.

STONE IN ONTARIO

The industries of interest in the context of this study are the producers of dimension stone, crushed aggregate, sand and gravel, and the manufacturers of products intended as substitutes for natural stone: namely, manufactured or reconstituted stone and lightweight aggregate. The relevant industry group, SIC 08, is comprised of two sub-groups: Stone Quarries, SIC 081 (subdivided by rock type), and Sand and Gravel Pits, SIC 082. The latest year for which data are available from Statistics Canada on these industries is 1987 [1]. The Statistics Canada publication "Quarries and Sand Pits" lists 27 establishments in the province of Ontario under "limestone quarries" (SIC 0812), none under "any other rock type," and 64 establishments producing sand and gravel under SIC 082. The listing under limestone quarries includes many producers of crushed stone, but few of the



Sawing of stone blocks at Arriscraft's Cambridge Plant. Photo courtesy of the Ontario Ministry of Natural Resources (photo by Tom Skudra)

TABLE 6-1 PRODUCTION OF STONE IN CANADA, BY PROVINCE (1986-88)

	1986		1987		1988P	
	(000 t)	($000)	(000 t)	($000)	(000 t)	($000)
Newfoundland	476	2,712	931	8,535	990	9,158
Nova Scotia	4,023	21,944	4,437	23,133	4,450	22,695
New Brunswick	2,344	13,064	2,878	15,934	2,960	16,280
Quebec	36,066	172,194	42,731	213,112	43,007	217,762
Ontario	45,477	226,130	52,412	273,032	51,000	280,500
Manitoba	4,100	26,831	3,760	15,959	3,500	14,000
Saskatchewan	..	..	2	4	2	4
Alberta	229	1,315	249	1,532	300	2,100
British Columbia	4,403	23,049	5,213	29,544	4,913	34,388
Northwest Territories	484	1,416	678	2,165	1,300	4,425
Canada	97,602	488,655	113,291	582,950	112,422	601,312

Source: Statistics Canada, ref. [2].

established producers of cut-stone products. This compilation is clearly incomplete, and unfortunately makes doubtful the accuracy of the data compiled on the industry group as a whole.

Some more recent information on stone production throughout Canada has been published by Vagt [2,3], indicating that Ontario is responsible for almost 50% of all stone production from Canadian sources (Tables 6-1 and 6-2). Data for 1987, published by the Ontario Ministry of Northern Development and Mines, present an overview of the stone industry in terms of general production and consumption (Table 6-3) [4]. It should be noted that these data include stone produced for purposes other than construction: notably, chemical process stone, agricultural stone, and fertilizer applications. According to Vagt, more than 90% of Canadian stone production is used in construction projects, and less than 10% is used for monumental or other purposes. Chemical uses for stone are limited almost totally to limestone and marble for the production of cement, lime, glass and metallurgical flux. This is reported to account for about 4% of production, while a further 2–3% is consumed in pulverized form as fillers and extenders or for agricultural purposes.

Table 6-4 shows the distribution of principal uses for stone in Canada among a number of building product types as reported for 1985 [2]. Not unexpectedly, aggregate uses such as road metal, concrete and asphalt predominate for stone types other than marble; marble's special properties make its use as building and pulverized stone more important.

DIMENSION STONE

The Ministry of Northern Development and Mines has recently produced a directory of building stone quarries in Ontario which lists 32 companies operating quarries in the province to produce building products other than aggregates. These quarries provide a wide range of materials, encompassing "flagstones" if foliated, or dimension stone if massive. Eleven companies are listed as producers of "polishable stone," five using granite and six, marble.

The dimension stone and stone products industry is composed of numerous small quarriers or processors, with limited vertical integration from quarry through to retail sales or installation. A few larger companies operate with an integrated structure and comprehensive sales policy. The dimension stone industry carries an image of low technology, low value-added, high seasonality, and discontinuous employment. In general, the larger companies, with higher sales and higher invested capital per employee, have more and broader expertise, and ability to deal with technological changes and product innovation.

A number of products sold throughout Ontario compete in applications where natural stone might typically be used. Notable are concrete-based paving stones and blocks, reconstituted (manufactured) stone, polymer-based concrete slabs, blocks or bricks and cultured marble. Because these products are made from such diverse materials, there are no data available to indicate the extent to which they are currently replacing stone in construction applications. (See Chapters 7 and 10 for more discussion.)

MINERAL AGGREGATES

According to the Ministry of Northern Development and Mines, 95% of Ontario stone production is crushed for use in concrete, asphalt, rip-rap and highway construction [5]. Crushed stone accounts for about 45% of Ontario's natural aggregate, with sand and gravel making up the remainder. The distribution of uses for sand and gravel aggregates in Ontario is shown in Table 6-5.

Mineral aggregates are supplied from many sources throughout the province in a competitive environment. The Aggregate Producers Association of Ontario represents approximately 140 members drawn from most of the major producers [6]. About 400 producing sites are in operation at

TABLE 6-2 CANADIAN PRODUCTION OF STONE AND MINERAL AGGREGATES, BY TYPES, 1975–1987

	1975		1980		1985		1987	
	(000 t)	($000)	(000 t)	($000)	(000 t)	($000)	(000 t)	($000)
Granite	11,470	34,913	39,983	140,914	17,219	95,424	16,957	110,569
Limestone	72,284	152,521	58,191	185,085	77,874	317,862	89,759	428,324
Marble	356	1,843	316	1,807	571	13,966	712	17,887
Sandstone	3,753	10,881	3,064	11,540	3,011	15,310	3,360	19,542
Shale	1,551	2,566	1,812	1,810	1,561	3,060	2,503	6,628
Sub-total	89,414	202,724	103,366	341,156	100,236	445,622	113,291	582,950
Sand & gravel					256,183	609,638	278,564	768,755

Source: Statistics Canada, refs.[2,3]

TABLE 6-3 REPORT OF ALL STONE PRODUCTION IN THE PROVINCE OF ONTARIO, 1987

Type of Stone	Sold		Consumed *	
	(000 t)	($000)	(000 t)	($000)
Dimensional Stone				
Building stone, rough	22	1,423	25	1,369
Lining open hearth furnace	1	65	0	0
Monumental and ornamental stone	6	928	1	112
Other (flagstone, etc.)	24	2,381	0	0
Total for dimensional stone	53	4,797	26	1,481
Chemical Process Stone				
Cement plants, Canadian	312	1,043	7,350	10,413
Flux in iron and steel furnaces	1,162	4,535	0	0
Flux in non-ferrous smelters	0	0	1	430
Glass factories	122	2,411	0	0
Lime plants, Canadian	1,399	4,995	494	5,229
Paint base	6	111	0	0
Soda ash	0	0	606	1,296
Total for chemical process stone	3,001	13,095	8,451	17,368
Pulverized Stone				
Agricultural, fertilizer plants	330	3,985	0	0
Asphalt filler	64	216	0	0
Brick	0	0	180	259
Calcite products	123	7,474	0	0
Carpet backing	15	243	0	0
Total for pulverized stone	532	11,918	180	259
Miscellaneous Stone				
Armour stone	76	660	0	0
Crushed stone for artificial stone	4	50	0	0
Drainage stone	8	37	0	0
Gabion	49	246	0	0
Mine backfill	0	0	432	1,767
Fill	97	457	0	0
Poultry grit	11	373	0	0
Rock wool	0	5	0	0
Roofing granules	353	7,182	0	0
Rubble and rip-rap	360	1,860	0	0
Screenings	95	131	0	0
Shale	26	20	669	1,329
Stucco dash	3	321	0	0
Total for miscellaneous stone	1,082	11,342	1,101	3,096
Crushed Stone				
Armour stone	8	69	0	0
Asphalt aggregate	4,115	21,631	466	2,170
Concrete aggregate	4,279	23,692	153	549
Dolomite	109	767	0	0
Drainage stone	125	567	0	0
Fill	5,401	21,993	0	0
Railroad ballast	198	1,063	840	6,490
Rip-rap	64	127	0	0
Road metal	30,496	125,530	667	2,236
Manufactured sand	27	92	0	0
Sewers	3	11	0	0
Sewers and driveways	21	136	0	0
Structural clay tile	0	0	29	17
Winter sand	276	1,580	1	5
Total for crushed stone	45,122	197,258	2,156	11,467
Totals	**49,790**	**238,410**	**11,914**	**33,671**

Source: Ontario Ministry of Northern Development and Mines, ref. (4)
* Refers to stone sold and consumed by stone producers.

TABLE 6-4 DISTRIBUTION OF PRINCIPAL USES FOR STONE IN BUILDING PRODUCTS, 1985

	Limestone		Marble		Granite		Sandstone		Shale	
	(000 t)	($000)	(000 t)	($000)	(000 t)	($000)	(000 t)	($000)	(000 t)	($000)
Building Stone:										
Rough	179	1,757	18	665	57	6,904	26	1,247	-	-
Other	14	741	-	-	9	500	2	97	-	-
Pulverized Stone:										
Whiting	27	1,487	-	-	-	-	-	-	-	-
Asphalt filler	48	495	-	-	193	2,257	-	-	-	-
Other	46	446	200	9,463	-	-	-	-	-	-
Crushed Stone:										
Artificial stone	-	-	10	203	-	-	-	-	-	-
Roofing granules	86	926	1	31	248	458	-	-	-	-
Stucco dash	11	553	3	105	4	328	-	-	-	-
Rubble & rip-rap	818	3,391	-	-	1,772	6,013	189	567	9	39
Concrete aggregate	7,042	30,613	32	220	1,506	6,313	213	1,300	-	-
Asphalt aggregate	5,715	24,103	-	-	1,150	5,803	123	614	-	-
Road metal	20,946	80,542	73	230	4,225	15,219	501	2009	220	764
Terrazzo	-	-	5	124	-	-	-	-	-	-
Other	24,324	96,295	124	802	17,219	15,747	1,712	8,040	1,129	1,772
Totals	59,256	241,359	466	11,843	26,383	59,942	2,766	13,874	1,358	2,575

Source: Statistics Canada, ref. [2]

TABLE 6-5 APPLICATIONS FOR SAND AND GRAVEL IN ONTARIO, 1986

Application	Consumption (000 t)
Roads	46,348
Concrete aggregate	17,574
Asphalt aggregate	5,081
Railroad ballast	123
Mortar sand	1,583
Backfill for mines	1,043
Other fill	13,896
Other uses	2,018
Total sand and gravel	87,666

Source: Canadian Minerals Yearbook, 1988, ref. [2]

any one time, although there are approximately 900 extraction sites in the province, representing over 2000 pit and quarry licences. The industry is composed of a variety of companies of widely differing size, from family businesses to major multinational corporations. Many producing companies are associated with other construction operations, with vertical integration into aggregate-consuming industries such as road-building and concrete production. Many of the small operations are part-time or seasonal in nature. Thus, the reporting of accurate data on aggregate production is difficult.

The technology for producing aggregates, either by crushing stone or extracting sand and gravel, largely consists of materials handling, screening and washing operations. Beyond a general trend towards increases in the size of unit operations, no basic changes are anticipated in the technical nature of the industry in the near future. The main problems faced by the industry relate to the sourcing of new deposits close to major market areas in the face of environmental controls and citizen opposition. At least one company is said to be considering dredging sand and gravel from Lake Ontario at the mouth of the Niagara River [7], and underground mining has been suggested as an option similar to the approach taken in some parts of the United States [8]. Aggregate is also recycled, largely for use in resurfacing highway pavements [8].

LIGHTWEIGHT (MANUFACTURED) AGGREGATES

In addition to aggregates from sand, gravel or crushed rock, so-called "lightweight aggregates" can be produced from expanded shale or clay, foamed or expanded metallurgical slags, or exfoliated and expanded vermiculite and perlite. In Ontario, lightweight aggregates are produced by National Slag Ltd., Hamilton, from pelletized blast furnace slag; expanded vermiculite and perlite are produced by W.R. Grace & Co. Ltd. at Ajax and St. Thomas. The Canadian Gypsum Company produces expanded perlite at Hagersville for use in gypsum plaster products. However, in general, the quantities of lightweight aggregates used in Ontario are small in comparison with the consumption of normal weight products (Table 6-6).

In spite of the abundance of clays and shales in the province, attempts to establish production of lightweight aggregates from them has not been commercially successful.

The last plant to produce such materials, located in Mississauga, closed in 1977. As has been pointed out by Guillet and Joyce, "...over the past 30 years, the production of expanded aggregate from clay and shale in Canada (and particularly in Ontario) has passed through one complete cycle of growth and decline, with little evidence of immediate recovery in the near term [9]." (See Chapter 11 for more information.)

DEVELOPMENTS IN STONE PRODUCTS

A number of products have been developed that simulate the appearance of solid natural stone. Variously termed "reconstituted," "manufactured" or "agglomerated" stone, these materials are all made by bonding natural aggregates, rock particles and fillers with some form of cementing material. Where the products differ is in the cementing process used. In some products, ordinary Portland cement is employed, while others are bonded by the use of autoclaved lime-silica cementing agents (Chapter 7). A group of product types related to polymer concretes (see Chapter 10) comprise epoxy or polyester resins heavily loaded with aggregates and fillers. The cement or lime-silica

TABLE 6-6 LIGHTWEIGHT AGGREGATE PLANTS IN ONTARIO

Company	Location	Commodity	Remarks
Canadian Gypsum Company, Ltd.	Hagersville	Perlite	Processed for use in gypsum plaster
National Slag Ltd.	Hamilton	Blast furnace slag	Used in concrete blocks and as slag cement
W. R. Grace & Co. of Canada Ltd.	St. Thomas	Vermiculite	Vermiculite, processed for use in horticulture and as loose insulation
	Ajax	Vermiculite, Perlite	Perlite processed for use in gypsum plaster and in horticulture

Source: Canadian Minerals Yearbook, 1988, ref. [3]

products are produced as blocks or slabs, with the appearance and texture of cut or rough-hewn natural stone. The polymer-based products are made in panels or cast units having the appearance of polished natural stone. Many types of stone aggregates, along with suitable fillers, are used in manufactured stone, depending on the aesthetic properties required.

Other manufactured products using natural stone in decorative ways are also available. A common form of block or panel available in Europe comprises a monolithic unit of backing concrete, faced with a decorative layer. Typical decoration is provided by exposed aggregates of pleasing shapes and colours, cast stone facings or pigments. An interesting variant of these products is a flooring system called "Natural Stone Carpet." Small (~5 mm) rounded, polished stone particles of a variety of rock types and colours are mixed with an epoxy resin and placed as a topping on a stable rigid sub-floor (concrete is preferred). The manufacturer claims that the appearance is similar to a knitted wool carpet.

Aside from its importance as an artist's raw material, potential new decorative building products can be produced from soapstone. The recent appearance on North American markets of soapstone fireplaces, and promotion by a Finnish company of soapstone's use in building materials indicates a possible interest for Ontario sources [10].

As will be discussed in Chapter 10, developments in concrete technology are leading to a renewed need for effective, low density aggregates. These materials are most likely to be synthetic in nature, produced either by expanding or pelletizing blast furnace slag, sintering pulverized coal fly ash or bloating natural clays. Developments in the production of lightweight aggregates from clays, and opportunites for Ontario minerals in this regard, are discussed in Chapter 11.

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7. Lime Products

- Limestone
- Dolomite
- Calcite
- Silica
- (Glass)
- (Sand)
- (Crushed rock)

At one time, lime was an important building material. Many early cements were made that hardened by the drying and carbonation of hydrated lime produced via the burning of limestone. Modern construction technology now uses very little lime, although some building products incorporate lime as an active ingredient (see below) and lime stabilization of soil is still an important application in engineering and civil construction.

INDUSTRIAL MINERAL CONTRIBUTION

Lime can be made by calcining a number of types of limestones, ranging in composition from dolomite, $(Mg,Ca)CO_3$, to almost pure high-calcium limestone, $CaCO_3$. Limestone is calcined at ~850°C, usually in a vertical or rotary kiln, on a rotary hearth, or on a traveling grate calciner. The product is a highly reactive form of calcium oxide (CaO), termed "quicklime." When quicklime is mixed with water it is said to be "slaked" and a hydrated product, variously termed slaked lime, hydrated lime or calcium hydroxide, $Ca(OH)_2$, is formed. When the limestone used is dolomite or contains significant quantities of magnesium, the product is termed "dolime" or dolomitic hydrated lime. Specifications normally require a minimum of 90% CaO (after ignition) for a high-calcium hydrated lime.

LIME IN ONTARIO

Although it is no longer used as a construction material, substantial quantities of lime are produced in Ontario at eight principal locations (Fig. 7-1, Table 7-1)[1]. In 1987, ~1.5 million tonnes of lime, valued at $100-million were produced in Ontario, accounting for ~66% of the total Canadian production [2]. Lime production in Ontario has been fairly flat for the past five years (Fig. 7-2). Substantial exports of lime are made from Canada, particularly to the United States, from which some small level of importation also occurs (Table 7-2). In 1984, Canadian exports of lime totaled ~186,750 tonnes, almost all of which went to the U.S., for a value of ~$14-million. In the same year, about 25,000 tonnes were imported at a cost of $2.6-million [3].

The principal industrial use for lime is in metallurgical processing. With increasing use of the basic oxygen furnace (BOF) in steel-making, lime consumption for fluxing has increased both in Canada and the U.S. Other major consumers are pulp and paper, water and sewage treatment, and various chemical process industries. In construction materials, lime is used in manufactured stone (Chapter 6), in masonry mortar (Chapter 10), as a minor additive to some glass batches (Chapter 12), and as an anti-stripping aid in hot-mix asphalt products (Chapter 13). Lime is also used as an activating agent for the blast furnace slag cement used in hydraulic mine backfill (see Chapter 9).

Lime plant, Spragge, Northern Ontario. Photo courtesy of Reiss Lime Company of Canada.

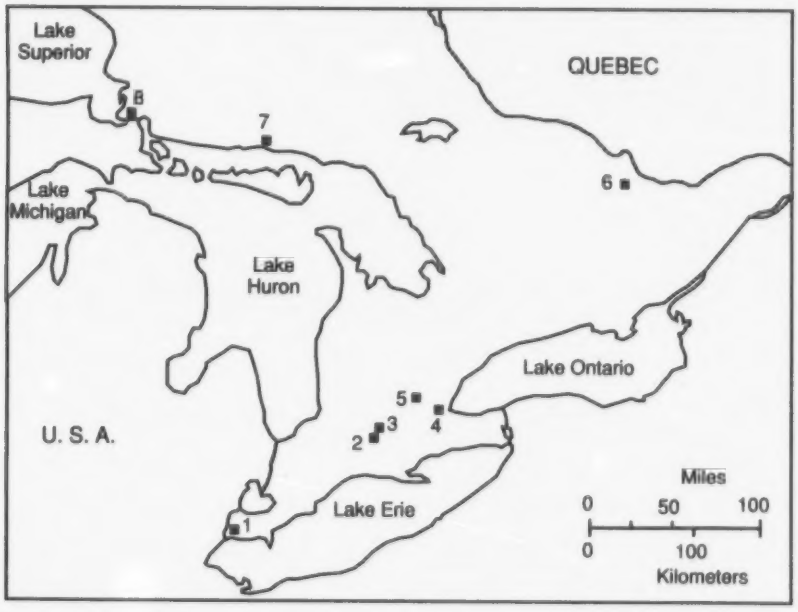


Figure 7-1 **Location of lime-producing plants in Ontario (see Table 7-1 for key).**

TABLE 7-1 THE ONTARIO LIME INDUSTRY

Company	Plant Location	Products
1. Allied Chemical Canada, Ltd.	Amherstburg	High-calcium*
2. Stelco Inc.	Ingersoll	High-calcium†
3. BeachviLime Limited	Beachville	High-calcium
4. Steetley Industries Limited	Dundas	Dolomitic
5. Guelph DoLime Limited	Guelph	Dolomitic†
6. Timminco Limited	Haley	Dolomitic*
7. Reiss Lime Company of Canada, Limited	Spragge	High-calcium
8. The Algoma Steel Corporation, Limited	Sault Ste. Marie	High-calcium and dolomitic*

Source: ref. [2]
* Production for captive use; † Hydrated lime produced also.

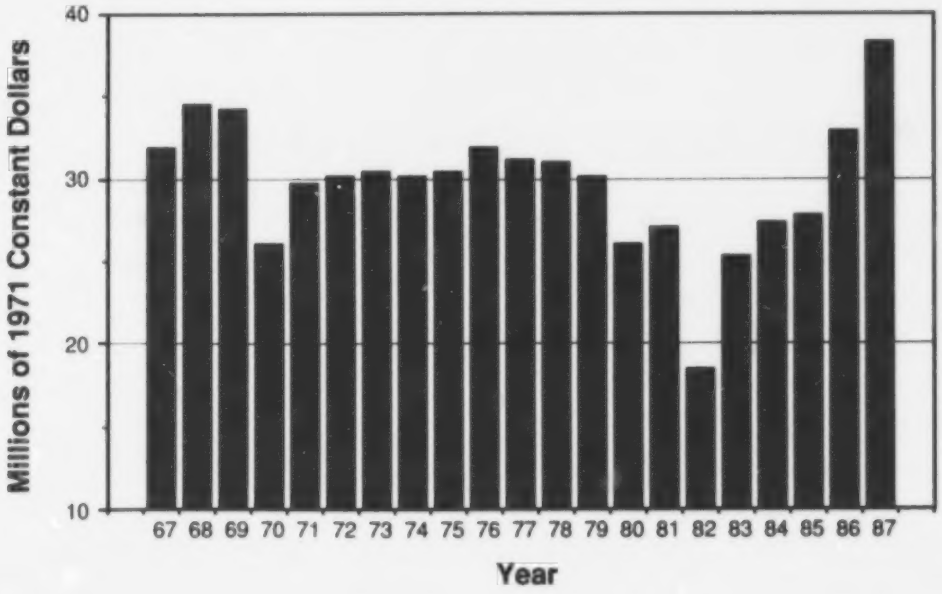


Figure 7-2 Lime production in Ontario, 1967–87. Source: ref. (1).

TABLE 7-2 LIME PRODUCTION AND TRADE, CANADA, 1986 AND 1987

	1986		1987	
	(tonnes)	($000)	(tonnes)	($000)
Production: [a]				
By Province:				
Ontario	1,511,191	111,567	1,537,582	100,540
Quebec	x	x	x	x
Alberta	192,704	16,196	212,943	19,194
British Columbia	123,109	10,339	120,098	9,954
Manitoba	x	5,540	x	8,118
New Brunswick	x	x	x	x
Total	2,242,577	171,359	2,330,071	167,566
By Type:				
Quicklime	2,069,043	157,037	2,140,793	150,971
Hydrated lime	173,534	14,322	189,278	16,595
Exports:*				
United States	189,354	16,966	163,627	13,668
Other countries	158	24	140	35
Total	189,512	16,990	163,767	13,703
Imports:*				
United States	44,858	4,307	42,269	3,642
Other countries	2,059	416	2,021	409
Total	46,917	4,723	44,290	4,051

Source: ref. [2] (a) producers' shipments and quantities used by producers;
x, confidential; * quicklime and hydrated lime.

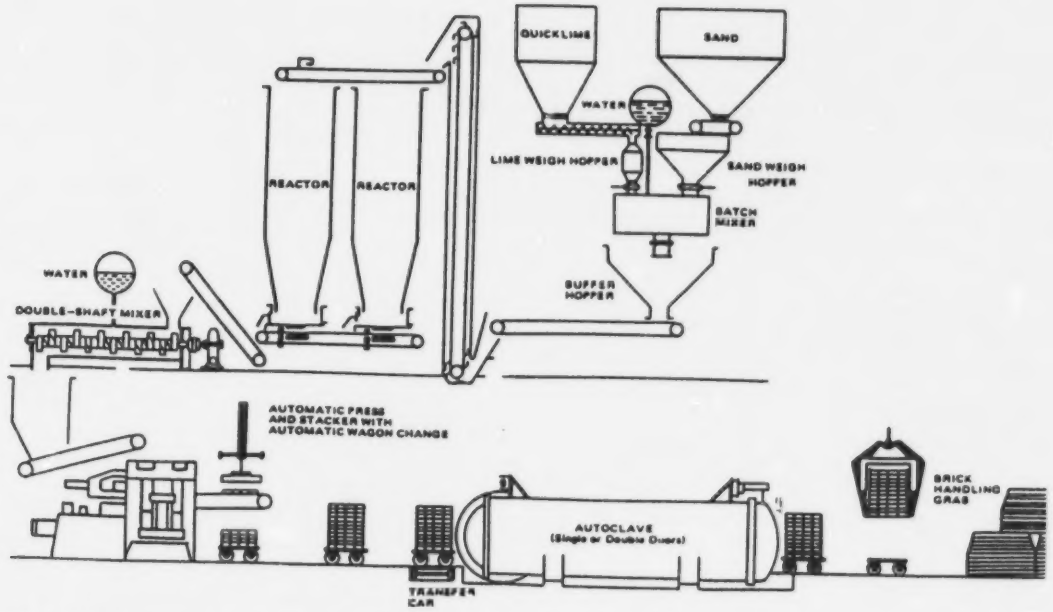
DEVELOPMENTS IN LIME PRODUCTS

Although not a new application, a substantial quantity of lime is used outside North America to produce autoclaved lime-silica masonry units (e.g. bricks, blocks and slabs). In Canada, earlier production of similar products, in the form of facing bricks, was not successful due to poor durability of some inferior products. Reports on the high quality of products now made in Europe suggest that significant technical advances have since been made [4,5].

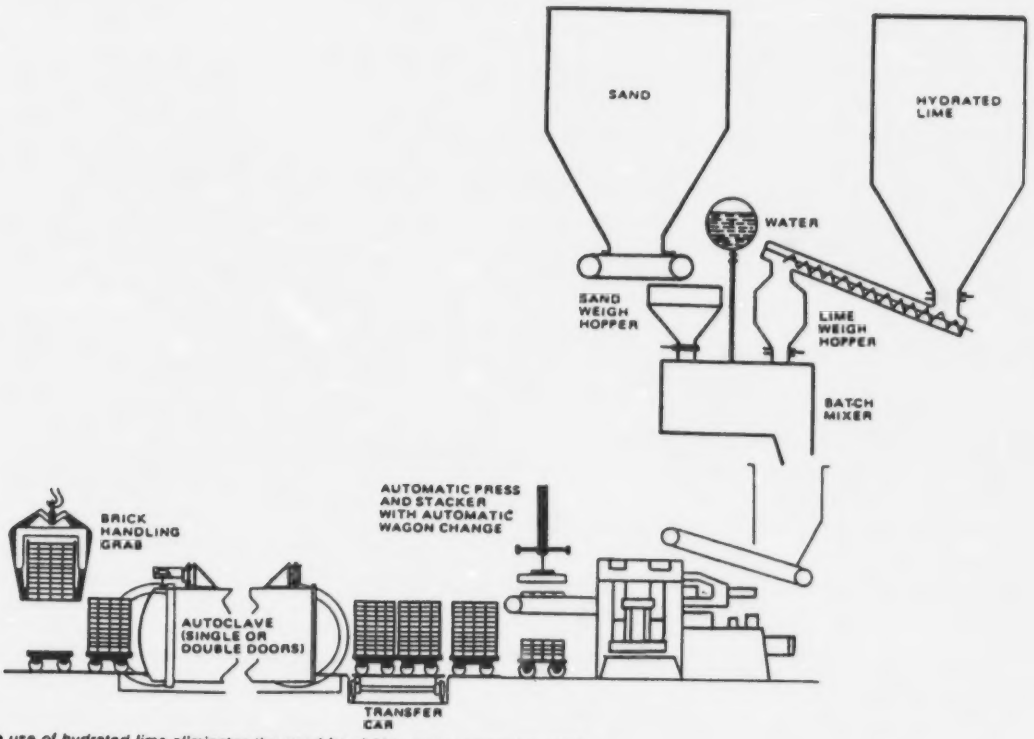
Calcium silicate, or sand-lime, masonry units are made by mixing lime (either in the hydrated form, or as quicklime) and sand, crushed siliceous rock, or sometimes fly ash, with sufficient water to permit the mixture to be moulded under high pressure (Fig. 7–3). The resulting "green" units are subjected to high-pressure steam in an autoclave which promotes a reaction between the lime and silica to form hydrated calcium silicates similar to those formed when water and Portland cement react.

Worldwide, more than 30 billion calcium silicate bricks are produced annually, with Europe, the Middle East, East Asia, Australia and Mexico as major consumers [4]. Use of calcium silicate brick in Europe dates from about 1866 and remains popular. Annual production in Britain is said to be in excess of 150 million bricks, with expansion among 5 major producers anticipated [5]. The bricks are finding particular application in renovation work.

The first sand-lime brick plant in the U.S. was built in 1901, and by 1927 more than 320 million bricks were being produced each year at more than 50 plants. In 1986, only one American producer, Grays Ferry Brick Co., N.J., remained [4]. Forster [4] attributes the North American decline of calcium silicate masonry to a combination of poor product quality and the market dominance of clay brick (see Chapter 11). One company in Ontario, Arriscraft Corpora-



When quicklime is employed, the reactor system looks like this.



The use of hydrated lime eliminates the need for slaking and a secondary mixer.

Figure 7-3 **Process flow-sheet for production of calcium silicate masonry from lime and sand. Source: ref. (4).**

tion, has developed its own process to manufacture high-density calcium silicate masonry units, at a plant in Cambridge. The units are produced for architectural applications, including structural components and vertical thin-wall exterior or interior masonry skin. The units, which are said to have high compressive strength and to tolerate severe weathering, have been used successfully on numerous public and private buildings in southern and eastern Ontario [6].

Durability is clearly the key factor in marketing calcium silicate masonry. Among modern products, drying shrinkage, thermal expansion, water absorption, thermal insulation and density all compare well with clay brick. However, the products are not durable to acid attack or to repeated saturation with salt water, and are not recommended for use in below-grade installations. Long-term durability of calcium silicate brick has been demonstrated extensively in Europe, where 60 years of exposure to wetting and drying, and freezing and thawing cycles have had little effect [4]. The improvement in performance of contemporary calcium silicate masonry over previous products is claimed to have resulted from "...a full understanding of all the elements which are essential... for a successful brick plant [4]." These are taken to include raw material specifications and processing. Research in Britain by the Calcium Silicate Brick Association and at British Ceramic Research Ltd. has lead to a number of improvements in performance over the past few years [5].

A related development in Japan has been the production of what is claimed to be a new material — precast autoclaved lightweight concrete (PALC). This material, about which very little technical information is to be found in public sources, was developed for use in factory-housing. PALC is variously described in the literature as being manufactured from "siliceous and calciferous materials [7]" and as consisting primarily of cement and silica or limestone [8]. This last description would not be consistent with the formation of calcium silicates by autoclave curing, since products of this type are produced from lime-silica reactions or those involving Portland cement. A schematic illustration of the process, as published by Misawa Homes Co. Ltd., is shown in Figure 7-4. The material appears to have contributed to the success of Misawa Homes in the Japanese modular housing market. Published information is too

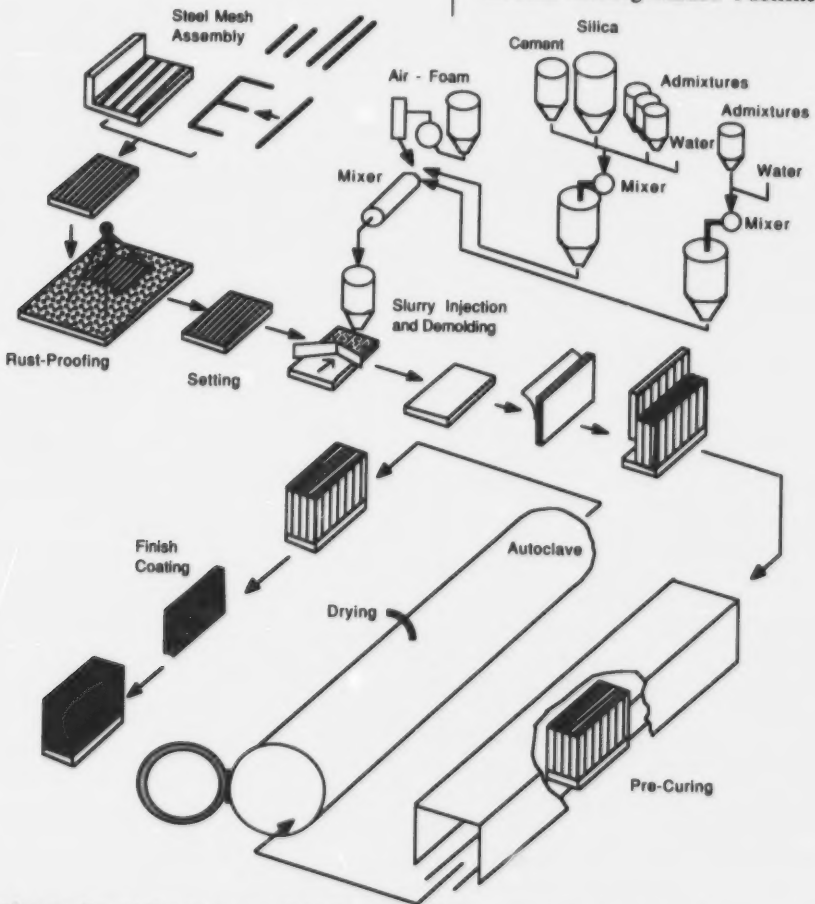


Figure 7-4 **Schematic of the Misawa PALC production process. Source: Misawa Homes Co. Ltd., company literature.**

limited for us to comment on the technical nature of the product, but it would appear that a more detailed investigation, including research and development work, is justified to evaluate the potential products of a similar material from Ontario sources.

PROSPECTS FOR INDUSTRIAL MINERALS

Short-term prospects for increased use of lime in building products in Ontario, beyond the levels currently employed, appear somewhat limited. Technical improvements in lime-sand masonry and the development of PALC in Japan suggest that the area of calcium silicate products is now worthy of further consideration in Ontario. The commercial viability of lime-silica masonry products depends on the proximity of both major building markets, and sources of suitable sand and lime. Based on European experience and a growing demand for low-density, insulating masonry forms, such items may be regarded as a continuing opportunity to expand markets for lime. We recommend that research into developing the new calcium silicate masonry products in Ontario is justified in respect of the potential to establish new markets for both lime and suitable silica sands.

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8. Gypsum Products

- Gypsum
- Anhydrite
- FGD gypsum
- Perlite, mica
- Vermiculite
- Fillers
- (Mineral wool)
- (Pumice)
- (Glass fibre)
- (Clay)

The earliest cements used in construction were made from mud, burnt limestone or burnt gypsum (calcium sulphate). The use of calcium sulphates as cements, mortars or exterior coatings (stucco) on structures was common practice among ancient civilizations in Mediterranean and Mid-Eastern regions. Ancient Egyptian stone buildings were mortared with burnt gypsum, which though less durable than lime, required less fuel for burning. In the arid climates prevailing in these areas, simple plaster cements were durable for long periods. In wetter climates, because gypsum is not a hydraulic cement (see Chapter 10), the use of stucco was limited to coating interior walls and ceilings. Until the early 1900s in North America, plaster was hand-placed on interior (or exterior) surfaces as a stucco finish. Sometimes, it was placed directly over masonry, concrete, or wooden laths. At times, animal or vegetable fibres were added for reinforcement, horse hair being a common constituent of many older, hand-plastered walls. In about 1910, the U.S. Gypsum Company began production of wallboard (see below), and by 1930 the drywall systems typical of current construction methods became available.

INDUSTRIAL MINERAL CONTRIBUTION

Gypsum is a naturally occurring sedimentary rock composed of calcium sulphate dihydrate ($CaSO_4 \cdot 2H_2O$). Its use in building products relies on its ability to be calcined (burnt) at temperatures in the range 120–150°C to the so-called hemi-hydrate ($CaSO_4 \cdot 0.5H_2O$), known variously as Plaster of Paris, stucco or, simply, plaster. In the calcined state, calcium sulphate hemi-hydrate is a cement that, when mixed with water, will set to form a hard plaster product.

Three types of plaster, made in different ways, are distinguished. When gypsum is heated in a kiln or kettle, the product is termed ß-hemihydrate or ß-plaster. This is the type of plaster used to produce wallboard (see below). Gypsum may also be dehydrated in an aqueous slurry at high temperature and pressure in an autoclave to produce a product which is termed α-hemihydrate or α-plaster. This material is used for casting gypsum products, art-work, medical casts, and as a dental cement. Finally, if gypsum is calcined at much higher temperatures (up to 700°C), a type of anhydrite (i.e. $CaSO_4$) is formed that may be used to produce a hard plaster termed "Keene's cement."

The principal modern use of gypsum is in the manufacture of wallboard products for drywall construction (see below). The second largest market for crude gypsum is as a retarder to control the set of Portland cement. Up to 5% by weight of gypsum is added during the clinker grinding operation at the cement manufacturing plant. Use in Portland cement may consume as much as 250,000 tonnes per year in Ontario. Smaller quantities are used as a substitute for salt cake in glass manufacture, as a soil conditioner, as a food additive, as fillers in plastic and paper

products (see Chapter 13), and as raw materials for producing special cements (see Chapter 9). The relative proportions of gypsum used in different applications are seen in the U.S. data given in Figure 8-1.

THE ONTARIO GYPSUM PRODUCTS INDUSTRY

Canada is the world's second largest producer of gypsum, and the largest exporter. Production in 1987 totaled ~8.8 million tonnes (Table 8-1) from nine corporate producers, half of which are foreign subsidiaries [1]. Most of the 4.3 million tonnes of gypsum exported from Canada each year goes to the United States, which obtains about 67% of its imported gypsum from Canadian sources. Finished gypsum products (lathe, wallboard, and basic products), valued at $120-million in 1987, were also exported from Canada. In general, the level of production of crude gypsum in Canada is in direct response to demand from the domestic and United States wallboard manufacturing industries, which, in turn, satisfy demand from the building construction sector.

Gypsum is mined in Ontario from the Salina Formation in the southwestern part of the province. Production from Ontario mines at Hagersville, Caledonia and Drumbo accounted or ~15% (1.4 million tonnes, valued at $18.7-million) of the total Canadian gypsum output in 1987.

Three companies control and operate the production of gypsum in Ontario: CGC Inc., Domtar and Westroc Industries. Each owns both mining and wallboard manufacturing facilities, all of which are located in the southwest of the Province (Fig. 8-2). The annual volume of gypsum production from Ontario sources in the 20-year period since 1967 is shown in Figure 8-3. Substantial increases since 1982 have resulted largely from increased building activity in the southern part of the province, the impact of which is particularly noted in the value of production considered

Although local supplies are used by each of the companies, crude gypsum is also brought into the province from major deposits that have been worked for many years in Nova Scotia and Newfoundland. Most of these mining operations are Canadian subsidiaries of United States companies or are owned and operated by Canadian producers, located in Central Canada. The Atlantic region accounts for over 75% of Canadian gypsum production and for the major portion of exports. Shipments are made from quarries in the region to wallboard and Portland cement plants in Quebec and Ontario. Crude gypsum produced by mines in Ontario is used on-site, or in the case of Westroc Industries Limited, is shipped from Drumbo to its Mississauga wallboard plant.

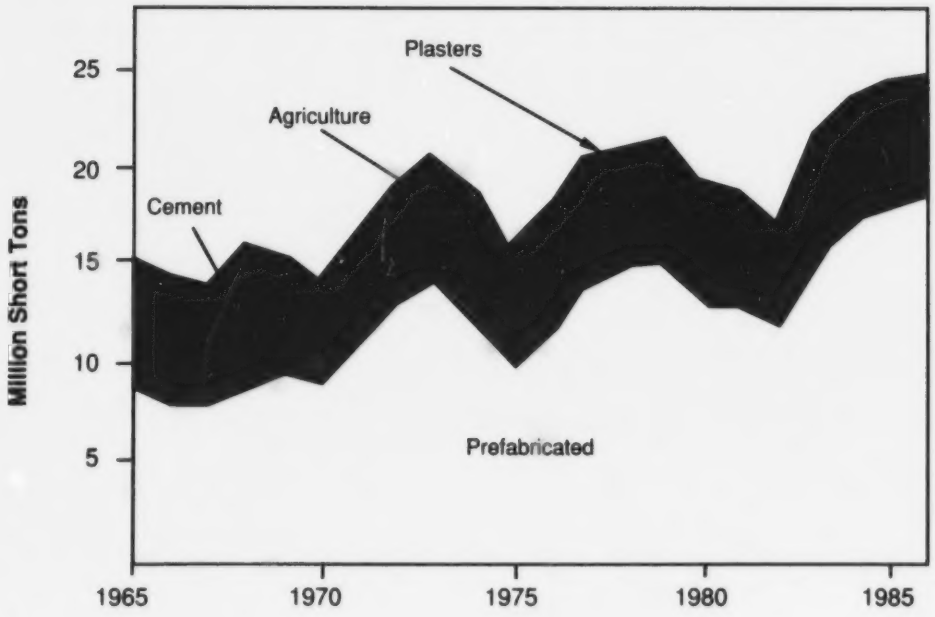

FIGURE 8-1 DISTRIBUTION OF SALES OF GYPSUM PRODUCTS IN THE UNITED STATES. SOURCE: REF. (1).

TABLE 8-1 CANADA, GYPSUM PRODUCTION AND TRADE, 1985-87

	1985		1986		1987P	
	(tonnes)	($000)	(tonnes)	($000)	(tonnes)	($000)
PRODUCTION (shipments):						
Crude gypsum						
Nova Scotia	5,479,275r	43,357r	6,263,988	50,126	6,034,477	51,010
Ontario	1,114,437	15,056	1,321,457	16,974	1,439,303	18,736
British Columbia	453,833	4,659	485,279	4,896	496,900	5,304
Newfoundland	517,621	6,096	484,576	6038	410,195	4,656
Manitoba	195,623	1,997	246,505	5,039	430,661	8,202
Total [1]	7,760,783r	71,164r	8,802,805	83,073	8,811,536	87,908
IMPORTS						(Jan.-Sept.)
Crude gypsum						
Spain	10,839	362	87,393	705	83,327	735
Mexico	92,769	3,022	101,376	3,268	90,423	2,804
United States	18,103	552	32,775	649	10,835	278
Hong Kong	91	3	100	3	161	3
Total	121,802	3,939	221,644	4,625	184,746	3,820
Plaster of Paris and wall plaster						
United States	24,622	5,833	21,294	5,154	18,138	3,727
France	-	-	-	-	-	-
United Kingdom	-	-	-	-	-	-
Italy	-	-	-	-	-	-
Other countries	8	2	13	3	2	1
Total	24,630	5,835	21,307	5,157	18,140	3,728
Gypsum lathe, wallboard and basic products						
	(sq. metres)		(sq. metres)		(sq. metres)	
United States	1,873,879	2,727	1,696,814	2,902	4,068,468	7,162
Other countries	44,846	87	94,206	154	69,830	98
Total	1,918,725	2,814	1,791,020	3,056	4,138,298	7,260
Total imports gypsum and gypsum products		12,588		12,838		14,808
EXPORTS						
Crude gypsum	(tonnes)		(tonnes)		(tonnes)	
United States	5,844,706	49,599	5,885,295	51,534	4,327,746	37,601
Other countries	35,728	266	21	3	183	84
Total	5,879,664r	49,865	5,921,982r	51,537	4,327,929	37,685
Gypsum lathe, wallboard and basic products						
	(sq. metres)		(sq. metres)		(sq. metres)	
United States	69,520,421	115,512	76,523,724	134,938	51,177,897	82,431
Saudi Arabia	44,592	121	-	-	-	-
Algeria	51,971	68	29,438	71	15,655	28
Bermuda	62,587	87	61,837	102	21,414	44
Other countries	290,569	641	75,037	144	28,796	73
Total	69,970,140	116,429	76,690,036	135,255	51,243,762	82,576
Total exports of gypsum and gypsum products		166,294		186,792		120,261

Sources: O. Vagt, "Gypsum and Anhydrite," in Canadian Minerals Yearbook: Review and Outlook, 1987, (Energy, Mines and Resources Canada, Ottawa, 1987), pp.33.1-33.8.; Statistics Canada. [1] Totals do not include gypsum produced of shipped for use by Canadian Portland cement producers. P Preliminary;-Nil; r Revised. Note: Totals may not add due to rounding.

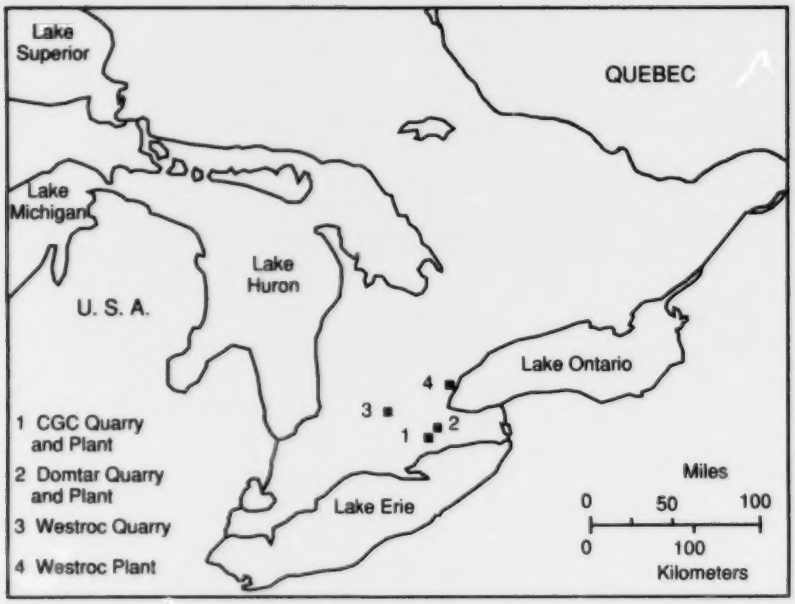

Figure 8-2 Location of gypsum mines and production facilities in Ontario.

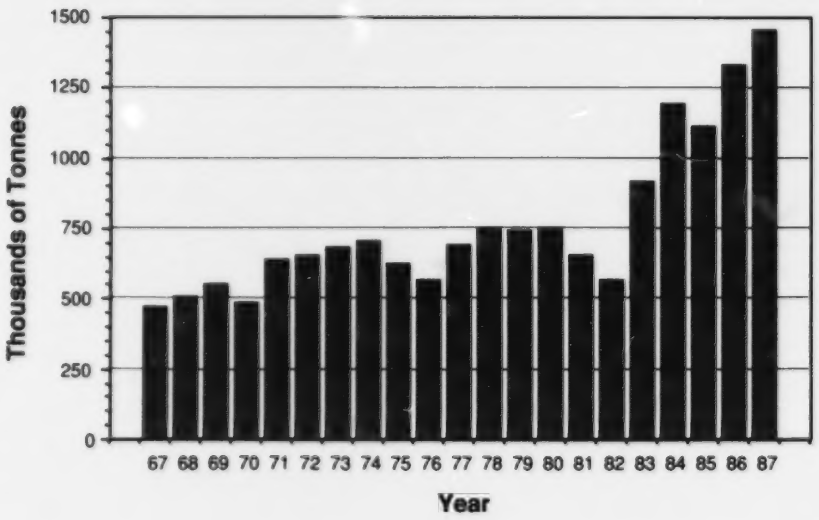

Figure 8-3 Volume of production of gypsum in Ontario in period 1967–1987. Source: Ref. (2).

At the present time, gypsum products in Canada are made entirely from natural mineral sources. However, worldwide there is great pressure to utilize gypsum from industrial waste sources, the major categories being from chemical gypsum from phosphoric acid production (phosphogypsum) and flue-gas desulphurization (FGD) residues from the power industry. In North America, the use of phosphogypsum has largely been eliminated because of problems with low-levels of radon emission from some sources. Other forms of chemical gypsum exist, and some have been considered for use but have not become commercialized. In Japan, with no natural gypsum supplies, the major sources are phosphogypsum and FGD residues. As a result of active attempts to reduce acidic precipitation in Europe, Scandinavia and Germany lead in the technology of using FGD residues [1].

WALLBOARD

Gypsum board, wallboard, sometimes commonly known as drywall, is the generic name for a family of non-combustible, sheet products consisting of a core of gypsum, occasionally with some added filler and foam, sandwiched between two layers of paper surfacing. In the manufacture of wallboard, crude gypsum is crushed, pulverized and calcined to form stucco. A slurry of stucco, water, foam, pulp and starch is then placed between two unwinding rolls of absorbent paper, the result being a continuous "sandwich" of wet board. After the stucco has rehydrated and hardened, the board is cut, dried, and stacked for shipment. The manufacture of wallboard and the drywall installation process are examples of mechanization in construction practice that have been instrumental in increasing productivity in an otherwise labour and skill-intensive operation.

The market penetration of gypsum wallboard was assisted by the low-cost residential construction boom which followed World War II. Gypsum board, which had been used in the construction of a number of temporary military facilities, became an attractive alternative to lath and plaster because it required less manpower to install and less skill to complete the job.

Initially, drywall construction was more readily accepted in the residential sector. The Toronto Dominion Centre, built in 1965, was the first major Canadian commercial project to use drywall. By the early 1960s, gypsum drywall, with the occasional assistance of wood panels, had almost totally replaced lath and plaster walls in residential construction.

Wallboard production in Canada currently consumes ~2.5 million tonnes of gypsum. Canada shares with the U.S. the distinction of having the world's highest per capita annual consumption of wallboard, at ~8 m^2 per person. Sales of wallboard closely reflect the number of housing starts, supplemented by renovation and repair. The current Canadian wallboard market is comprised of residential (40-45%) and commercial (25%), with the balance made up by renovation [1]. Enhanced levels of renovation and repair are expected to offset some of the consequences to the wallboard market resulting from the general decline in housing starts anticipated over the next decade (see Chapter 4).

Though the main use for wallboard is in conventional wood frame housing, increasingly it is being used in the United States in mobile homes and prefabricated panelized construction. In the commercial sector, gypsum wallboard is favoured because it provides a fire-resistant cladding for office partitions and steel work. There is also growth in its use in shaft wall, stair well, and ventilator construction. According to Benbow [1], the decision to include lining in the shaft walls of the recently constructed Sears building in Chicago doubled the quantity of wallboard required for the building.

Wallboard has three principal points of convenience:

- it is relatively simple to install in new construction, though more work is required in renovation or on repair projects;
- it is non-combustible;
- it provides a flat smooth finish upon which surface coatings or fabrics can be added for decoration.

However, wallboard has two principal weaknesses:

- it is brittle and can resist very little tensile or flexural stress;
- it is not waterproof, although some degree of water resistance can be imparted by surface finishes or coatings.

Since its rise to dominance in the interior cladding market, the basic wallboard product has undergone few technical changes beyond minor modifications and improvements. Equally, except for the use of screws rather than nails, and the introduction of steel studs rather than timber for framing, little has changed in the way drywall is constructed or used. In the area of product improvement, the earlier forms of gypsum board have evolved to encompass a variety of functions in addition to simple interior cladding. Water-resistant gypsum board is used in bathrooms and other areas where humidity may be a problem. Vinyl-faced gypsum board is being widely used in commercial construction to reduce maintainance and cleaning costs. Aluminum-covered board is used as a vapour barrier material. Other types include gypsum backing board for interior walls or ceilings that are to receive acoustic or other cladding; gypsum sheeting board for residential use; and the 1-inch thick gypsum core board used for face walls and other special applications.

Most of the technological developments by the wallboard industry in recent years have focused on reducing the energy costs of production. Grinding, calcining and drying are the main energy-using steps in the manufacture of gypsum wallboard. In the interests of energy conservation and process cost reduction, significant savings have been

achieved by recycling heat from calcining kettles for use in preheating and in board drying and by combining the grinding operations. There is also a trend towards using less calcined gypsum in board while using greater amounts of foam and more effective dispersing agents to obtain lighter weight units with equal or greater strength. Product diversification and development has largely been directed to overcoming the basic weaknesses of the traditional product to improve strength and water resistance (see below).

DEVELOPMENTS IN GYPSUM PRODUCTS

Gypsum is an inexpensive, cementitious binder with good fire retardance. However, it has low tensile and flexural strength, poor water resistance and loss of structural integrity when exposed to fire. Much of the recent gypsum product development effort conducted internationally has been directed to improving these properties by modifications that make it less brittle, stronger, and more waterproof. Areas of development in gypsum products have been of four general types:

- modification of board products to obtain improved properties,
- development of cast gypsum items such as blocks,
- use of calcium sulphates as fillers and fibres in plastics,
- use of calcium sulphates for special cements (see Chapter 9).

Modified Board Products

Faced with competition from Portland cement and plastic cladding materials, both of which are waterproof, the gypsum producers have developed board products that can be used in wall panels and wall systems. These may incorporate an element of water resistance or otherwise integrate some other function into the wall system, such as thermal or sound insulation. In other areas, effort has been focused on producing structural elements that can replace wood. In both of these types of products, composite materials — which are based on gypsum as a binder — can be produced by three approaches: dispersing fibres or fillers in gypsum plaster, incorporating polymers in the plaster matrix, or laminating gypsum plaster board with other materials.

Fibre Reinforcement

The use of fibres, notably animal hair, in gypsum plaster has a long history that now extends into a number of products where reinforcement is used to improve tensile and impact strength. The use of glass fibres in gypsum products to form glass-reinforced gypsum (GRG) is widely reported [3] and many patents have been issued covering a broad range of applications and methods of production. Addition of glass fibres to gypsum at up to 10% by mass has been used to eliminate the need for a paper covering in board products [4,5]. The fibres are said to provide the toughness normally associated with a paper/gypsum laminate.

Glass fibres have also been used in the formation of contoured gypsum sheet or board. A process developed by USG Corp. [6] employs a GRG slurry cast onto a bed which can be shaped to produce contoured forms. Slurries of GRG with 5–10% glass fibres can be sprayed or rolled to form lightweight ornamental drywall sections [7]. Glass reinforcement is also commonly used in gypsum ceiling tiles and panels.

Mineral fibres have been used widely to reinforce gypsum products. Mitsubishi Petrochemical Company has patented a process in which a clay mineral with a hollow fibrous structure (sepiolite) and various other components are used to produce a gypsum product with high strength and odour-absorbing properties [8]. Heat-treated mineral fibres have also been incorporated into gypsum to improve both bending and compressive strengths significantly [9]. A patent held by the University of Toronto [10] describes the use of glass or metal fibres woven into a cloth for reinforcement to improve the bending and tensile strength of the product. Pumice, fly ash, expanded clay and rice straw have been used to produce gypsum composites with superior thermal and sound insulating properties [11].

Chemically treated wood fibres, called "wood wool," have been added as reinforcement to cement-gypsum products [12], in which the cement serves to improve strength in a humid environment. A gypsum board reinforced with wood flakes has been developed in Scandinavia and introduced to the British market by Bison. This is one of a number of products that have been developed using wood waste as a component of gypsum particle and flake boards. These products are said to be less expensive than conventional particleboard, more fire-resistant, and free from emissions of organic vapours. Waste paper fibres from recycled newsprint are used in gypsum fibre boards manufactured by a number of companies in Europe. Other materials, largely at the research stage of development, have incorporated nylon [13] or carbon [14] fibres as reinforcing agents.

Gypsum board products incorporating insulating properties have been developed widely, mostly in the form of laminates (see below). In a different approach, Hilmer et al. [15] have developed an insulation board containing expanded perlite, gypsum and newsprint.

Polymer Modification of Gypsum

Polymers have been used for many years to improve the moisture resistance, freeze-thaw durability, abrasion and

impact resistance, and flexural and compressive strength of both cement and gypsum products. The incorporation of polymers to modify gypsum products is generally accomplished by pre-set modification, polymer impregnation, or surface modification.

Pre-set modification involves addition of a polymer to the gypsum slurry before it has set. Polymers such as polyvinyl alcohol or urea-formaldehyde are either mixed with the dry plaster before adding water, dissolved in the mixing water, or added as a monomer to the slurry. In each case, polymerization occurs as the gypsum is hydrating. Depending on the flow properties of the slurry, the mixture can be cast, sprayed or extruded and allowed to set. Polymer addition to the gypsum slurry can significantly improve the strength and impact resistance of the product [16,17].

Gypsum can be modified with a polymer by impregnating the pre-hardened, porous matrix with a monomer which, once it has intruded into the pores of the gypsum, is induced to polymerize by chemical means, the application of heat, or radiation. The most commonly used polymer for impregnation is methyl-methacrylate. The resulting polymer-impregnated gypsum can have vastly improved impact and abrasion-resistance, strength and water resistance [18].

A third approach to combining the benefits of polymers with those of gypsum is surface modification (coating) of normally set or reinforced gypsum bodies with polymer. This is done largely to improve water or impact resistance. The polymer functions only as a barrier to moisture or or to harden the surface. Because the untreated gypsum core of the coated products is still prone to weakening when exposed to moisture, the coated products cannot be subjected to such severe conditions as the impregnated products can withstand.

A water-impervious coating for gypsum walls has been described as consisting of an acrylic pre-polymer, alkyd resin, bitumen and glass-fabric [19]. The coating significantly improves the water vapour diffusion resistance of the substrate. Several U.S. patents have been obtained for polymer impregnation/coating processes. One describes a gypsum board coated with a mixture of polyvinyl acetate, wax and water which improves the water resistant properties of the board such that concrete can be cast against it with little moisture penetration [20]. The USG Corp. has patented a process to coat gypsum wallboard with a mixture of sand and acrylic or styrene-butadiene emulsion [21]. The resulting product, designed for exterior use, was described as showing good adhesion and resistance to degradation.

Laminated Gypsum Products

Traditional paper-covered wallboard is an example of a laminated gypsum product in which the paper provides the flexural strength and some impact resistance, and the gypsum core functions only to provide compressive strength. Recently, developments have been made by laminating various materials with differing properties to a gypsum core. In a British patent [22], polyethylene sheets are laminated between foamed polystyrene and regular gypsum wallboard to produce a board with low water vapour permeability and good heat insulating properties. Similarly, a U.S. patent [23] describes a decorative laminated sheet material formed by covering gypsum board with a paper sheeting which was saturated with various polymers. Decorative paper was then applied to give a product with improved stain and abrasion resistance.

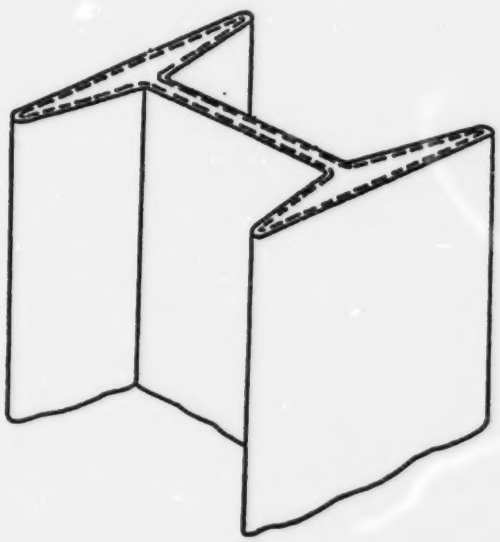

Figure 8-4 **Extruded I-channel made from a gypsum composite. Source: ref. (27).**

Panels in which gypsum is used as backing or core are available commercially with a variety of properties. Patented and proprietary plastic laminates are often bonded to gypsum wallboard and other core materials. Profiled steel- or aluminum-clad sandwich assemblies are also available with interior sheets of plasterboard for insulation. Sound and thermal insulation is provided by laminating dense insulation slabs with gypsum plasterboard as a composite internal lining for walls and ceilings. High strength, steel-laminated, glass-laminated, and glass roving-reinforced gypsum boards have also been developed [24,25].

Various methods have been reported to produce artificial wood using polymers in conjunction with gypsum, hemihydrate or anhydrous calcium sulphate. Complex multi-component reinforced laminates, some with polymer modification have been developed for use as structural members. British Plaster Board Industries (BPB) has developed a process to produce structural gypsum components [26]. A sheet of inorganic fibres, embedded with a urea- or phenol-formaldehyde copolymer, is covered with a gypsum slurry containing perlite or vermiculite. The coated sheet is turned up at the edges to form a channel, and a second sheet is applied to the top side of the product. Figure 8-4 shows an example of an extruded I-channel, formed from a gypsum composite that can be used as studding. A process to form an extruded gypsum product modified with resins such as polyvinyl acetate or vinyl esters and vermiculite, clay or bentonite has been patented [27]. The mixture may be aerated before extrusion to reduce its unit weight.

A French patent [28] describes a Japanese product composed of polymer-modified gypsum which is wound onto a spool and fused together to produce a wood-like material. The polymer-gypsum mixture is passed through rollers and pressed into a thin sheet which is wound into large rolls. Once these have cured, they are cut at various angles to produce different wood grain effects (see Fig. 8-5). The articles can be stained to give the appearance of wood.

Each of these products can be considered as prototypes of gypsum-based materials which are targeted as wood replacements. Their development indicates an interest in the industry to produce materials that can be used where wood is now the material of choice. Applications would be for such items as door and window frames and base boards. The advantages, apart from displacing increasingly expensive wood products, would be in the reduced quantity of flammable material in a building.

Both the laminated and the water-resistant board products are directed to bringing gypsum into the exterior cladding market and to satisfying the needs for factory-produced systems such as closed panels. They are examples of the industry's response to threats to their market share coming from plastic and cement-based products. They also indicate another step in the now-established direction of factory-made building systems and units that was established when the industry originally developed wallboard and drywall systems.

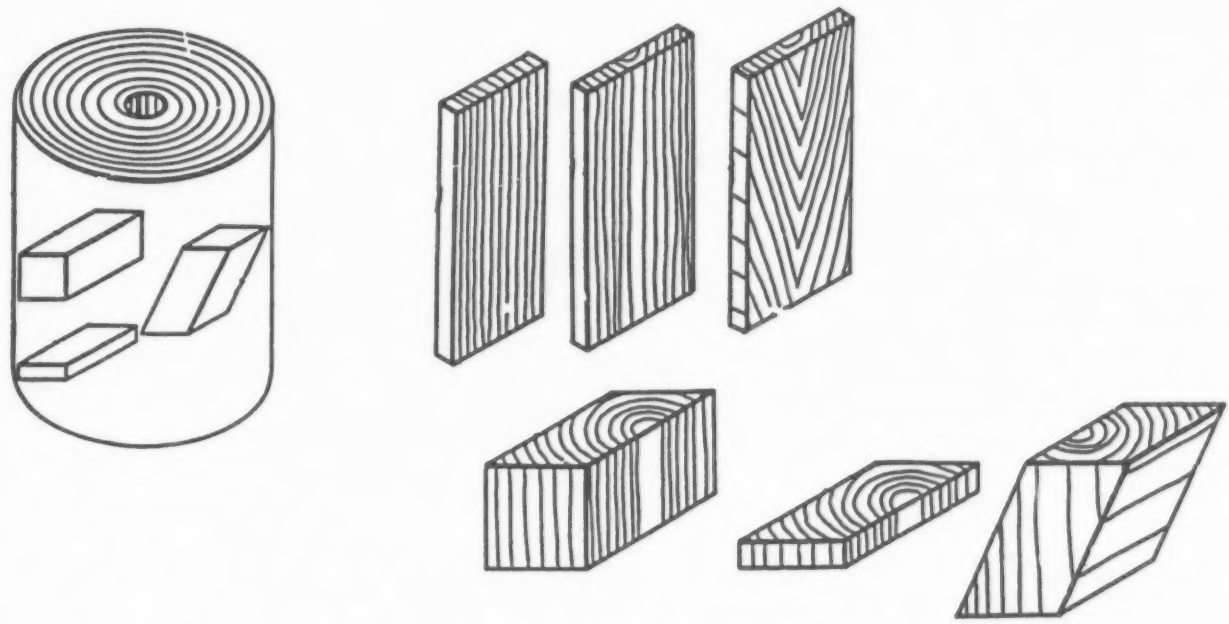

Figure 8-5 **Artificial woodgrain effects obtained by sectioning a gypsum composite. Source: ref. (28).**

Fire-Resistant Gypsum Products

Though gypsum is not flammable or combustible, it loses strength on exposure to heat. Various types of fire-resistant gypsum boards have been manufactured, containing reinforcing materials which help the board maintain structural integrity in a fire. Fire-resistant gypsum board containing mica (muscovite), glass fibres, foaming and accelerating agents has been described [29]. Other patented fire-resistant gypsum boards contain glass fibres, mineral fibre wool or unexpanded vermiculite. With the general trend to remove asbestos from buildings, gypsum is also being used widely in alternative fireproofing products. In addition to gypsum board products, gypsum or plaster, sometimes in combination with other cementing materials, is frequently used in sprayed-up coatings for fireproofing of structures.

W.R. Grace and Company has developed a fireproof coating for metal surfaces consisting of calcined gypsum mixed with vermiculite, cellulose, glass fibres and water [30]. In a related product, waste newspaper pulp is combined with mineral wool fibres and gypsum to produce a strong, fire resistant building board in a patent acquired by Cape Board and Panels Ltd. [31]. A Canadian patent, held by Lafarge S.A., describes a gypsum board reinforced with ettringite fibres that is fire resistant for four hours, as compared with two hours for the board without the fibres [32].

Fire resistance and heat-insulating properties have also been associated with GRG, often with additional properties provided by other constituents: use of glass monofilament reinforcement (4% by mass) has been claimed to improve shock resistance in a fire-resistant gypsum board [33]; and incorporation of perlite has been described by Evans et al. [34] to give good insulating and fire-resistant properties. Generally, glass-fibre reinforcement improves the strength of the otherwise structurally weak product. Fire-resistant, honeycomb panels were patented by Bell Fibre Products Corp. [35] in which 2% of short glass fibres are incorporated in a gypsum/resin bead slurry.

Cast Gypsum Products

Wallboard and the multitude of sheeting, cladding and surfacing products developed from gypsum all require complex manufacturing plants that are viable only for large production volumes. Products made by casting can be produced at various process scales suited to market demand. Casting can be accomplished at the jobsite where, for example, gypsum plaster has been suggested for cast-in-place, self-leveling floors and sub-floors [36,37].

The simplest cast gypsum products are masonry partition blocks which are widely used in Europe. Partition blocks made from plaster are produced in Germany to a standard specification (DIN 18.163) as prefabricated building elements for lightweight, non-load-bearing internal walls. According to Erlenstradt [38], the gypsum block is the least expensive partition material used in German construction practice. The blocks are made in a moulding plant, and they can be profiled for surface appearance, while at the same time offering excellent fire protection. Blocks are considered one of the three major gypsum products in Switzerland, and are an important component of the industry in France, where two of the three major companies operate production facilities to supply local and Benelux markets. Such products could be manufactured on almost any convenient scale for local use where a source of gypsum is available. They offer a possible product for gypsum exploitation in Northern Ontario.

Two markets of small volume have developed for decorative items as a result of fashion and renovation trends. Decorative plasters, in the form of cast cornices, columns, mouldings and fireplace surrounds, are available. A British company, Aristocast, supplies the do-it-yourself market with a range of products cast from fibre-reinforced gypsum plaster. A complete kit is supplied including adhesives, fillers, paint, mitre blocks and templates. A ceiling system based on ornate sculptured plaster is available in Ontario, imported from Italy. Such products could readily be produced from local raw materials by a small, entrepreneurial industry. Similar product types could be made from dense hard α-plaster, modified by polymer additions, or possibly from Keene's cement.

Flooring

Although gypsum board is normally considered for use in walls and ceilings, a system of remedial treatment for existing timber floors that should be of interest to the renovation and conversion market is offered by British Gypsum (a member of the BPB Industrial Group). The system is described as being particularly applicable where floors must be upgraded to provide sound insulation and fire resistance [39]:

> "The system employs metal channel sections with integral resilient strips which are fitted over the top of the floor joists and located on metal clips. 19 mm Gyproc plank is cut and fitted between the joists resting on the channel flanges. Mineral wool mat is laid between the joists to rest on resilient bars which are fixed to the underside of the joists. Ceiling linings of either 19 mm Gyproc plank and 12.5 mm Gyproc wallboard or two layers of 15 mm Gyproc wallboard are screw-fixed to the resilient bars. The floor is completed by screw-fixing flooring down through the 19 mm plank into the flanges of the metal channel sections."

PROSPECTS FOR INDUSTRIAL MINERALS

The gypsum building products industry is clearly instigating some changes in the types of product offered to the construction market. In addition to wallboard, its primary product, the industry appears to be responding to a number of market factors including:

- Competition from cement- and plastic-based products is leading to active development of stronger boards and weatherproof cladding products. These products are also suited to factory building of mobile homes and panel construction systems.
- Concern over safety and comfort in buildings is leading to the development of fireproofing, sound and heat-insulation products. The fireproofing value of gypsum is increasingly emphasized in company literature. The major virtues of gypsum in fireproofing are the cooling effect of water evaporation as gypsum decomposes, the reduced fuel load, and the lack of any toxic fumes during combustion.
- The anticipated decline in new housing starts, and the changes in the pattern of house-owning over the next few years are likely to influence the development of products suited to the renovation market. Some of these have started to appear as commercial or developmental materials.

Most of the developments in gypsum technology are likely to impact principally on the companies presently in the gypsum industry, rather than providing new opportunities for independent sources of gypsum minerals. This is to be expected, because most of these developments are the product of the industry's own research and development activities.

Two areas that appear to have potential for new business development by companies outside of the established gypsum industry are the production of cast gypsum masonry from small batch process operations, and the manufacture of gypsum products reinforced with wood waste. Both approaches would appear to have some potential for exploitation of gypsum deposits in the north of the province as a way to provide materials for local construction, rather than for wider distribution to the building industry as a whole. Other opportunities for industrial mineral producers exist in supplying such ancillary minerals as vermiculite, mica, perlite and mineral wool fibres to gypsum product manufacturers.

Areas of future development in gypsum products can be expected to concentrate on the non-traditional applications. Among these, notable developments are expected in the production of "artificial wood" or substitutes for wood products based on gypsum composites, and the use of FGD residues in gypsum products. Recently announced plans by Ontario Hydro for the reduction of acid gas emissions by using "scrubbers" at some of its thermal plants may make FGD residues available in the province [40]. Writing in relation to FGD residue use in Britain, Benbow notes that [1]: "Its use in a new gypsum-based furniture board is...being evaluated, and additional markets are expected...in the future."

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9. Hydraulic Cements

- Limestone
- Clay, shale
- Silica
- Sandstone
- Gypsum
- Anhydrite
- Fluorite
- Magnesite
- Bauxite
- Pozzolans
- (Fly ash, slag)
- Dolomite

Cements are materials which have the property of hardening from a fluid state in such a way that they can be used to bind together stone, sand, inorganic fillers or wood to form composite structures. The earliest cements were probably made from mud, burnt lime and burnt gypsum. While these were adequate for construction in arid climates, and, in some cases, ancient structures based upon their use survive to modern times, their weakness was an inability to resist water, particularly in damp climates or in structures designed to contain or control water. An alternative class of binders — so-called "hydraulic" cements — form hardened stone-like masses when mixed with water and are able to harden to a stable and durable mass, even when totally immersed in water. All hydraulic cements are derived from processed industrial minerals.

Hydraulic cements were known to the Romans under the Latin name *caementum*, which also probably described what is known in modern times as concrete. These cements were based upon mixtures of lime and pozzolans of natural origin (see later discussion), notably volcanic ash from the region of Pozzuoli. The first major departure from the use of lime/pozzolan cements began in 1756 with the discovery that a hydraulic cement could be made by burning limestone that contained clay. By 1824, the technology of hydraulic limes had developed to the point where a stonemason, Joseph Aspdin, invented Portland cement — named because of the similarity of appearance between the hardened product and a type of sedimentary building stone found on the Isle of Portland in Britain.

Portland cement is now among the most widely used construction materials in the world, with annual U.S. and Canadian production totaling more than 90 million finished tons in 1988 — on a mass basis, more than twice as much Portland cement is used in construction than the total of all other materials, including wood, steel, plastic and aluminum. Portland cement is the principal binder used in concrete, which is a mixture of coarse and fine aggregates, bound by a hardened paste that is formed through chemical reactions between water and Portland cement to produce a rock-like mass. In addition to its use in concrete, Portland cement finds applications in the manufacture of numerous building products, including bricks and blocks, cladding, drain and water pipes, and roofing, or as a binder for other minerals in such products as asbestos cement sheet and pipe. These constitute a miscellany of product types which may be classified as cement-based building materials (see Chapter 10).

TABLE 9-1 TYPES OF HYDRAULIC CEMENT

Main Types of Cement	
Type	*Composition*
Portland	≥95% clinker
Composite	≥65% clinker
Portland slag	≥65% clinker, ≤35% slag
Iron Portland	70% clinker, 30% slag
Blast furnace slag	≤65% clinker, ≥35% slag
Portland-fly ash	≥65% clinker, ≤35% fly ash
Portland pozzolan	≥65% clinker, ≤35% natural pozzolans (e.g. diatomite, cherts, tuff, clays, shales)

Special Types of Cement		
White	Aluminous	Road and runway
Sulphate resisting	Masonry	Asbestos
Low heat	Pozzolan with lime	Coloured
Supersulphated	Alkali resisting	Slag with lime
Oil well	Expansive	

Source: Cembureau compilation, ref. [1]

While Portland cement is, by far, the dominant cementing agent used in construction, there are several other cementitious materials which are now an essential part of modern cement and concrete technology. In the U.S., for example, there are 38 various types of standardized cements, including no fewer than 8 different types of Portland cement with >95% clinker [1]. A convenient division of the standardized cement types has been given by Cembureau, the European Cement Association, into "main" types and "special" types (Table 9-1). Dominant among the main types of cement are Portland cements and Portland cements incorporating various levels of so-called "supplementary cementing materials" (i.e., natural pozzolans, fly ash, slag and silica fume) which are used as mineral admixtures. Of growing importance also are special hydraulic cements, many of which are based on chemistries which are different from that of Portland cement (e.g. aluminous, magnesia, regulated-set, supersulphated and expansive cements). Not all standardized cements are continuously produced and some are only made to order.

In this section, hydraulic cements are considered first as commodities. Their application in concrete technology and in the manufacture of cement-based products will be examined in Chapter 10. It will be seen that, in various ways, the manufacture of cements provides opportunities for significant added value to a range of industrial minerals.

PORTLAND CEMENTS

Portland cement is produced by the high-temperature firing of an accurately proportioned mixture of calcareous material (generally, limestone, chalk or marl) and a source of silica and alumina (usually clay or shale), which contains an adequate amount of iron oxide to act as a fluxing agent. The mixture of minerals is ground to a fine powder and fired in a rotary kiln at ~1450°C. The material discharged from the kiln is a fused, chemically complex "clinker," consisting of a mixture of calcium silicates ($3CaO \cdot SiO_2$, $2CaO \cdot SiO_2$) and aluminates ($3CaO \cdot Al_2O_3$, $4CaO \cdot Al_2O_3 \cdot FeO$). The cooled clinker is mixed with gypsum (4–5% by mass) as a set-controlling agent, and is pulverized to a fine powder to form Portland cement. At this stage, limestone (to a maximum of 5%) may also be included as an additive for some Portland cements.

By close control of the raw mix, the burning conditions and of the use of additives in the clinker-grinding procedure, finished cements displaying various properties are produced. Five basic types of Portland cement are produced by Canadian cement manufacturers: Normal, Moderate, High-Early-Strength, Low Heat and Sulphate-Resistant Portland (CSA Types 10, 20, 30, 40 and 50, respectively). Smaller quantities of masonry cements are also produced, containing various mixtures of Portland cement, finely ground high calcium limestone (35–65%), hydrated lime and/or a chemical plasticizer. Portland cement and masonry cement used in Canada should conform to the specifications of CAN3-A5-M83 and CAN3-A8-M83, respectively [3].

Cement types manufactured in Canada, but not covered by the CSA standards, generally meet the appropriate specifications of the American Society for Testing and Materials (ASTM).

It should be noted that the cement industry, while being engaged in a manufacturing activity which strictly involves the pyro-processing of industrial minerals, is classified by Statistics Canada as a component of the industrial minerals industry.

The Ontario Portland Cement Industry

Nine cement-producing companies operate plants in Canada. Of these, five have facilities in Ontario, located in the southern and southwestern parts of the province (Fig. 9-1), with a total clinker production capacity of ~7.1 Mt per year distributed among seven plants with a total of sixteen kilns (Table 9-2). The total industry capacity to grind cement in Canada is reported at 17.9 Mt per year, and it is estimated that 12.2 Mt were produced in 1987 for a utilization of 72%; equivalent utilization in Ontario was estimated as 83% [4,5].

There has been substantial growth in the cement industry following the 1982 recession (Table 9-3 and Fig. 9-2), to the extent that cement manufacturing was the most profitable industry in Canada in 1987, with an average return on investment of 35.5% [6]. Cement production in Ontario is very efficient, largely as a consequence of the high level of new capacity that has been installed in the province in the past few years. Exports of cement and clinker from Ontario are mainly to the United States, in particular to the states of New York, Vermont, Michigan and Minnesota. Canadian cement production efficiencies and a relatively strong American dollar continue to make Canadian cement and clinker competitive.

Eighty-three percent of the Canadian cement industry is now foreign-owned [4]: St. Lawrence Cement is controlled by Holderbank Financière Glaris of Switzerland; Lafarge Canada Inc. is owned by Lafarge Coppée of France; and Lake Ontario Cement is owned by a French company, Societé des Ciments Français. (Both St. Marys Cement Co. and Federal White Cement Ltd. are private Ontario companies.) An advantage of this extensive foreign input to the industry is the connection that it provides to the research and development establishments operated by the parent companies in Europe.

Because of the ready availability of limestones and shales with suitable chemical properties throughout the southern part of the province [2], the cement plants largely produce their own raw minerals, with little need for purchase of materials (other than fuel) from other sources.

Limestone for the Lafarge Canada, Bath plant is quarried on-site and silica is supplied from Potsdam sandstone at Pittsburgh, Ontario, about 65 km east of Bath; iron oxide and gypsum are purchased from Hamilton and Nova Scotia, respectively. The Lafarge Woodstock plant obtains limestone on site, silica from Indusmin Division of Fal-

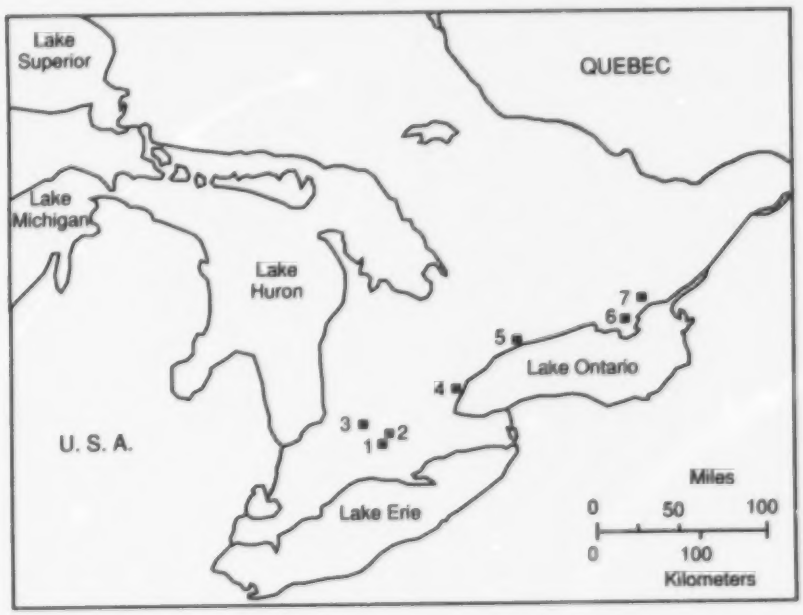

Figure 9-1 **Location of cement plants in Ontario (see Table 9-2 for key).**

TABLE 9-2 CAPACITY OF CEMENT PLANTS IN ONTARIO, 1987

Company	Plant Location	Kilns No.	Kilns Process*	Capacity (tonnes) Grinding	Capacity (tonnes) Clinker
Lafarge Canada Inc.	2 Woodstock	2	W	590,000	557,000
	7 Bath	1	Dx	1,102,000	1,040,000
Federal White Cement Ltd.	1 Woodstock	1	D	195,000	162,000
Lake Ontario Cement Ltd.	6 Picton	4	D	949,000	1,568,000
St. Lawrence Cement Inc.	4 Clarkson	3	2W,1D	1,764,000	2,051,000
St. Marys Cement Co.	5 Bowmanville†	2	W	869,000	662,000
	3 St. Marys	3	2W,1D	882,000	1,092,000
Ontario Total		16		6,351,000	7,132,000

Source: Portland Cement Association, ref. [5] * W, wet; D, dry; Dx, dry preheater; † major expansion announced.

TABLE 9-3 CEMENT PRODUCTION AND TRADE IN CANADA, 1985-87

	1985 (tonnes)	1985 ($000)	1986 (tonnes)	1986 ($000)	1987P (tonnes)	1987P ($000)
Production: [a]						
By Province:						
Ontario	4,092,753	283,677	4,437,345	343,086	5,201,000	413,671
Quebec	3,093,545	183,794	3,249,209	190,289	3,600,000	216,900
Alberta	1,142,852	148,881	949,354	113,371	1,075,000	132,061
British Columbia	988,498	74,818	1,071,108	73,696	1,247,000	88,288
Manitoba	342,963	35,725	415,192	43,733	451,000	48,868
Saskatchewan	..	12,237	..	16,684	..	17,904
Nova Scotia	..	21,079	..	25,430	..	39,509
New Brunswick	..	12,366	..	9,526	..	9,285
Newfoundland	..	8,779	..	8,530	..	9,541
Total	10,192,442	781,356	10,611,223	824,345	12,205,000	976,027
By Type					(9 month)	
Portland	9,254,535	735,769	9,929,135	778,321	..	..
Masonry [b]	937,907	52,588	682,088	46,023	..	..
Exports:						
Portland cement	2,485,699	128,356	2612,648	135,000	2,035,002	99,590
Prestressed concrete structures	..	26,100	..	37,961	..	28,875
Basic products	..	55,976	..	58,284	..	45,990
Imports:						
Portland cement	213,768	16,380	225,544	16,115	254,359	15,89
White cement	4,129	547	4001	491	5,225	490
Aluminous cement	5,419	1,999	6,539	1,964	10,493	1,746
Cement, nes	28,931	3,077	51,023	5,633	35,845	3,645
Basic products, nes	..	4,185	..	4,544	..	5,260
Clinker	94,941	2,975	203,026	7,430	118,090	4,343

Source: ref. [4]
(a) producer's shipments plus quantities used by producers; (b) includes amounts of clinker and other cement; P, preliminary; .. , not available; nes, not elsewhere specified.

conbridge Ltd., iron oxide from Stelco Inc. and gypsum from southern Ontario. For its Mississauga plant, St. Lawrence Cement Inc. obtains limestone from Ogden Point, 160 km east of Toronto on the shore of Lake Ontario; gypsum is purchased from Nova Scotia or from southern Ontario mines. Common clay from glacial drift is used as a source of silica and alumina in the manufacture of grey Portland cement at Woodstock and St. Marys by the St. Marys Cement Company. Federal White Cement Ltd. purchases high-calcium limestone from BeachviLime in southern Ontario, silica from the Indusmin Division of Falconbridge Ltd., low-iron kaolin from Georgia and gypsum from CGC Inc.

At Picton, Lake Ontario Cement Inc. operates one of the largest cement plants in North America. The four-kiln plant supplies cement to its Ontario markets and clinker to its associated companies in the United States — Rochester Portland Cement Corp. in New York State, and Aetna Cement Corporation in Michigan. Lake Ontario Cement Inc. is well integrated into the concrete products field through the Building Products Group. The acquisition in 1986 of Universal Concrete Products Inc., of Columbus, Ohio, provides a major extension of the company's current market area as far south as the Carolinas. Also, acquisitions of ready-mix operations in North Bay, Ottawa and Maitland were initiated and completed in the period 1985–1987. St. Lawrence Cement Inc.'s acquisitions of cement plants in New York and Maryland in 1984-85, along with cement distribution terminals, increased capacity substantially; their capacity in the United States remains at about 1.1 Mt. Most recently, added capital expenditures were made, principally to upgrade production facilities and the concrete ready-mix fleet. The company continues to ship into the northeastern region of the U.S. from its Canadian plants.

A typical feature of the Canadian cement industry is its vertical integration into related construction and construction materials fields. Many cement manufacturers also supply ready-mix concrete, stone, aggregates and concrete products such as slabs, bricks and prestressed concrete units. For example, Lafarge Canada Inc. owns two cement plants in Ontario, a number of aggregate quarries through its subsidiary Standard Aggregates, and two ready-mix companies (McCord Co. and Richvale Block and Red-D-Mix). The company has other interests in concrete brick and precast plants, and in the distribution of blast furnace slag cement and fly ash, both being materials that compete with Portland cement in some markets.

SUPPLEMENTARY CEMENTING MATERIALS

Modern concrete practice frequently employs one or more of four types of mineral constituents added to the mix to partly substitute for Portland cement:

- pozzolans of natural origin
- fly ash from coal-burning power plants
- ultra-fine silica from ferrosilicon manufacturing or similar sources
- granulated or pelletized slag from iron blast furnaces

In Canada, these have been collectively termed "supplementary cementing materials," and are defined by CSA as "...materials that, when used in conjunction with Portland cement, contribute to the properties of the hardened concrete through hydraulic or pozzolanic activity, or both [8]." The alternative ASTM description of a pozzolan, both of natural origin and in the form of industrial by-products, such as slag or silica fume is "...siliceous and aluminous material which

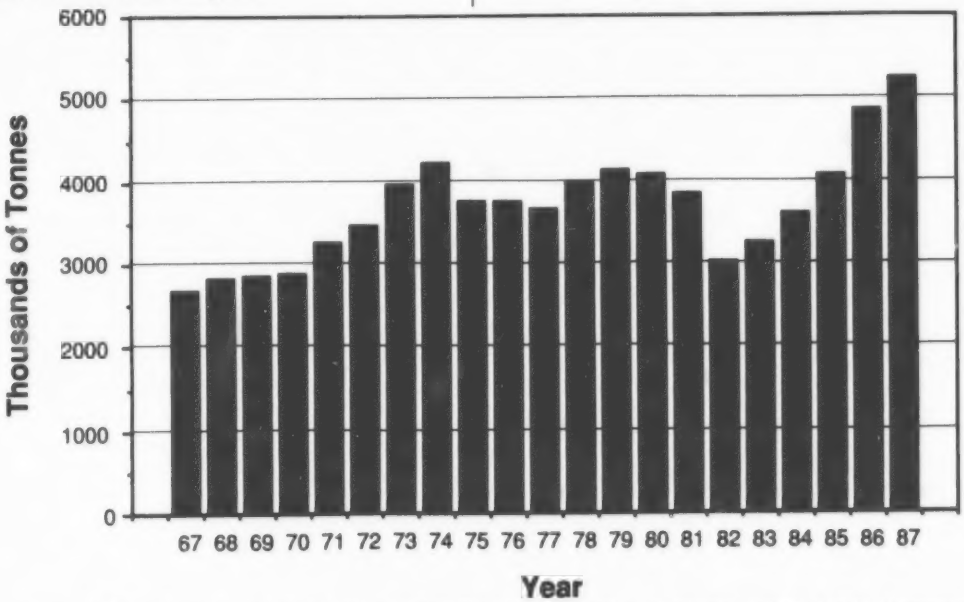

Figure 9-2 **Trends in volume of production of Portland cement in Ontario, 1967-1987. Source: ref.(7).**

in itself possesses little or no cementitious value but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties [9]."

Supplementary cements are currently used in two alternative ways: pre-blended with Portland cement at the manufacturing plant in a product known as "blended" cement; or, as is the more common practice in Canada, added along with the cement, aggregates and water as a component of the mix at the concrete batching plant. The applicable Canadian standards in both cases are CAN3-A362-M83 and CSA A23.5-M1982, respectively [8].

With the exception of natural pozzolans, supplementary cements do not currently fall under the general purview of industrial minerals. This is really a matter of classification since, like Portland cement, they are all formed by the high temperature thermal modification of minerals, albeit in an indirect way, such that they are considered as by-products. However, since supplementary cements are now central to modern cement and concrete technology — highlighted by the fact that in combination with Portland cement they are now classified as "main" types of cement by Cembureau [1] — they must be included in our examination of the potential impact of this sector on the province's industrial minerals producers.

Natural Pozzolans

Natural pozzolans are of four types [10]:

- volcanic glass
- volcanic tuff (the product of natural hydrothermal alteration of volcanic glasses)
- calcined clays and shales
- chert and opalitic silica, including diatomite

Before the invention of Portland cement, mortars and concretes, made by mixing natural pozzolans and lime, were in use throughout the world. There is evidence that Minoan structures built about 1500–2000 B.C. contained crushed potsherds (i.e. calcined clay) in a lime mortar. The use of natural pozzolan-lime concrete has been discovered in a lining for a water tank dating from 600–700 B.C. in the ancient Greek city of Camiros, on the island of Rhodes.

The Romans widely practised aspects of building construction developed earlier by the Greeks and may have used pozzolans from crushed tiles before they discovered the pozzolanic properties of volcanic ash. They seem to have carried their knowledge of preparing moisture-resistant mortar from pozzolan-lime mixtures to all parts of their empire including Germany, France, and Britain. The Rheinisch trass in Germany, a volcanic tuff, was probably discovered during the Roman period. In addition to concrete lining for aqueducts, pozzolan-lime concrete was widely used by the Romans for the construction of cisterns, waterfront walls, and brickwork in buildings. One of the most famous buildings of the era, the Pantheon, has walls seven meters thick made of pozzolan-lime mortar thinly faced with brick, while the large dome (43-meter span) is cast solid in concrete containing pumicite pozzolan.

Natural pozzolans are widely used in construction in China, Greece, Italy, India and Mexico. They have been used in modern times in North America; however, in Canada, and, in particular, in Ontario, the use of natural pozzolans has largely been superseded by the use of fly ash from the thermal power industry or slag from the steel industry. The reader is referred to other sources for more detailed information on pozzolans of natural origin [10].

Fly Ash

Fly ash is a fine particulate by-product of the combustion of pulverized coal in thermal power plants. It is removed by dust collection equipment from the combustion gases before they are discharged into the atmosphere. The term "fly ash" was coined in the electrical power industry in about 1930. The first comprehensive data on its use in concrete in North America were reported in 1937 by Davis et al. [11]. The first major practical application was reported in 1948 with the publication by the United States Bureau of Reclamation of data on the use of fly ash in the construction of the Hungry Horse Dam. Fly ash was first used in Ontario in construction of concrete hydroelectric dams. Worldwide acceptance has followed slowly upon these early efforts, and growth of fly ash use has been particularly noticeable in the wake of the rapid increase in energy costs (and hence, cement costs) that occurred during the 1970s.

Fly ash is now a common constituent of much of the structural concrete used in Ontario. It is used both for reasons of economy and for the properties that it imparts to concrete. When properly employed as an ingredient of blended cements or as an admixture to Portland cement concrete, fly ash can improve the performance of both fresh and hardened concrete. In fact, some of the technical advantages made possible by the use of pozzolans in concrete are unattainable when ordinary Portland cement is used alone. The advantages include improvement in workability, reduction in heat of hydration, increase in watertightness and ultimate strength, and enhanced resistance to sulphate attack and to alkali-aggregate expansion. A particular advantage of the use of fly ash in construction has been in producing high-strength concrete for high-rise structures where it has been accepted as an essential ingredient [12].

Of the ~2.5 million tonnes of fly ash produced each year in Canada, an estimated 900,000 tonnes are produced in Ontario [13]; however, for reasons of quality and access of supply, most of the ash used in concrete in the province is

now imported from the United States (Wisconsin, Michigan, New York). Fly ash produced in Ontario is used for engineering and civil works as fill, and in some cases, in mine backfill materials in the north of the province. The supply and distribution of fly ash in Ontario is largely controlled by the major cement manufacturing companies.

Blast Furnace Slag

Blast furnace slag was first used as a cement in Europe in 1863 and has a long history of application in concrete that is exposed to seawater. After 1970, especially following the 1971-72 oil crisis, granulated slag became more widely used in North America. Supplementary cementing materials made from blast-furnace slag differ somewhat from pozzolans in the way that they are used in concrete, to the extent that they can be incorporated at levels of more than 70% substitution for cement [13].

Slag is produced as a waste product in the manufacture of iron. It may be cooled from the molten state, in which it is discharged from the blast furnace, by a number of methods. When it is deliberately forced to cool rapidly, a glassy material is formed that can be finely ground for use as a supplementary cementing material.

Slag cement produced from granulated (or pelletized) blast-furnace slag and Portland cement is used in Ontario in all grades of concrete, from ready-mixed basement material at 20 MPa strength, to high-strength grades. Slag was used along with silica fume in the 70 MPa concrete supplied to the Scotia Plaza project (see below). Slag-lime binders containing no Portland cement are used successfully by the Ontario mining industry for consolidation of hydraulic backfill, but are not used in building construction. So-called "supersulphated" cements containing slag are discussed later.

The entire Canadian domestic supply of blast-furnace slag, suitable for cement use, is produced at two centres in Ontario: Reiss Lime Company of Canada from its Spragge, Ontario, grinding plant, using granulated slag from The Algoma Steel Corporation Ltd.'s Sault Ste. Marie plant (capacity 200,000 tonnes/year); and Standard Slag Cement Co., from its Fruitland, Ontario, grinding plant, using pelletized slag from Dofasco in Hamilton.

Silica Fume

Silica fume is an ultra-fine particulate collected from the exhaust gases discharged from the smelters used to produce silicon metal and ferrosilicon alloys [15]. Silica fume was first used experimentally in concrete in Norway early in the 1950s. The first documented use in structural concrete was in 1971, at the Fiska smelting plant in Norway. Other applications have followed in Sweden and Denmark. Outside Scandinavia, the use of silica fume has been growing since 1980, and it has been used in ready mixed concrete in Canada since 1981.

Silica fume is an extremely reactive and efficient pozzolan and is normally used at levels of less than 10% in a wide range of concrete products. It has found application in [16]:

- normal, low-grade concrete where the required strength can be obtained at unusually low cement content;
- ultra high-strength concrete, where compressive strength in the range of 100-120 MPa at 28 days is desired;
- in factory-produced concrete where rapid development of early strength is required to increase production rates;
- in shotcrete and in concrete for service in structures where seawater, chloride or chemical attack are possible.

The most valuable properties of silica fume in concrete are: (a) its ability to accelerate strength development; and (b) its effect on reducing the porosity and pore structure of concrete to render it exceptionally impervious to water and deleterious chemicals. In these respects, the use of silica fume can be considered as one of the most important new developments in concrete technology. In particular, in relation to the trends in construction discussed in Chapter 3, silica fume has the technical potential to contribute:

- strength and durability in factory-made concrete, or on-site industrialized concrete products;
- overall durability improvements in concrete;
- a role in inducing early strength in cements used for repair and renovation projects.

Silica fume has been used recently in much of the concrete supplied for high-rise construction in Ontario. One of the most notable recent buildings in which silica fume was used is the Scotia Plaza Tower, Toronto. The core and columns of this 68-storey office tower were built using 70 MPa concrete containing silica fume. Self-elevating jump forms and pumped concrete permitted a remarkable building rate on this project of 2.5 days per floor, with forms stripped after 11 hours.

As distinct from fly ash and slag , which are widely available in much of Ontario, the world supply of silica fume is relatively limited. Total worldwide production is estimated at about 1 million tonnes. Exact data have not been available on the supply of silica fume in North America, but estimates are that in 1981, a total of 16,500 tonnes was available in Canada; a corresponding figure for the United States was ~250,000 tonnes. Norway is one of the world's largest producers of silica fume with an estimated production of 132,000 tonnes in 1981 [17]. Material for the Ontario market comes from SKW Canada Inc., Bécancour, Québec and from New York State. With the limited quantities available and the strong demand, the price of silica fume

sold into the construction industry in North America has recently escalated, with prices of more than $1250/tonne being noted [18]. Meanwhile, the tonnage being incorporated into concrete continues to increase.

SPECIAL CEMENTS

There are numerous hydraulic binders in the "special" cements category (see Table 9-1), some of which can be regarded as modified Portland cements (e.g. white, masonry, and oil well cements), while others are not based on Portland cement at all and develop strength through the formation of hydrates other than calcium silicates (e.g. aluminous, magnesia, and calcium sulphate cements). Since many of these special cements have characteristics (such as rapid setting and strength development, expansivity) not found in Portland cements, they often command premium prices. Though little used at present in Canada, there are indications that they are a growing segment of the cement market, with varied potential uses: for example, in concrete repair (where rapid-setting is often required), for concrete work at low temperatures, and for the production of prestressed concrete.

In this diverse group, five types of special cements have a more substantial history and are of particular interest because they are produced from, or involve, industrial minerals which differ from those required for the manufacture of Portland cement:

- high alumina cements
- regulated-set cements
- calcium sulphate and supersulphated (slag/calcium sulphate) cements
- expansive (sulphoaluminate) cements
- magnesia and phosphate cements

Thus, opportunities for added value for the raw materials might be presented. Some information on less common, non-traditional cements is given at the end of the section.

High Alumina Cement

High alumina cement (HAC) has been known since the beginning of this century [19] as part of efforts to develop alternatives to Portland cement. It is manufactured by the fusion (at ~1600°C) of calcareous minerals (typically, high-calcium limestone or chalk) and a source of alumina, most commonly bauxite. The clinker, which consists primarily of the cementitious compound calcium monoaluminate, $CaO \cdot Al_2O_3$, and other minor aluminates and silicates, is harder than Portland clinker and consumes more energy during grinding to cement. Iron-containing compounds are also present in the clinker and account for the typical dark colour in some sources of the material. White HAC is produced from low-iron raw materials for the manufacture of castable refractories.

The annual production of HAC is only a small fraction of that of Portland cement. In 1975, world production was estimated at ~600,000 tonnes, excluding the Soviet Union [20]. High alumina cement is not currently produced in Ontario, and ~10,500 tonnes valued at $1.75-million were imported into Canada in 1987 [4]. It is known by several trade names including Ciment Fondu, Lumnite, Lightning and Secar 250.

The hydration of calcium aluminate under normal temperature conditions involves a complex binding mechanism to form, as is the case for Portland cement, an interlocking network of crystalline hydrates — in this case, the aluminates CAH_{10} and C_2AH_8 [20,21]. This hydration reaction is strongly exothermic and, as a result, HAC has been used successfully for construction under cold weather conditions — in fact, the manufacturers promote its use at temperatures below -3°C, and claim successful results as low as -40°C. Although HAC does not set faster than Portland cement, it does develop strength and evolve heat at a much greater rate after initial set has occurred.

A deterrent to the wider use of high alumina cement materials in concrete has been the so-called "conversion" reaction, a deleterious reaction which occurs when the principle hydration phase of the hardened material, CAH_{10}, transforms into the stable cubic hydrate C_3AH_6 and alumina gel. This transformation, which is influenced by a number of factors such as temperature, water to cement ratio, stress and the presence of alkalis in the mix, can lead to a significant reduction in the strength of the concrete [20-22]. However, in the past, many of the problems blamed on conversion of the HAC were more likely attributable to poor workmanship and inappropriate use [22]. Like Portland cement concrete, HAC concrete requires good workmanship and attention to detail, particularly in terms of air-entrainment and controlling the critical w/c ratio during mixing and placement. This appears to be the area where the most misunderstanding of the material has occurred.

By virtue of its good resistance to chemical attack, HAC finds many specialized industrial applications, such as flues, boiler stacks, ash sluices, coal hoppers, effluent tanks and sewers, and in many plants, including dairies, breweries, tanneries and oil refineries. Another major industrial use of HAC is in refractory concretes for high temperature uses, where it is sintered in service (hence preventing any possible conversion). High alumina cement, along with calcium sulphate and Portland cement, is also used as component of various proprietary formulations for quick-setting cements used for patching and other repairs. There is currently active interest in using HAC in sand-cement grouts for use at low temperatures in the Canadian North [23]. Another recent development in the use of high alumina cement comes from the

Building Research Establishment in the U.K. where there have been reports that blast-furnace slag has been used successfully with HAC to prevent the conversion reaction [24].

High alumina cement possesses many of the properties required for a rapid-hardening structural or repair cement, or for applications under cold weather conditions, provided the concrete is designed accordingly to prevent frost damage and deleterious conversion during service.

Regulated-Set Cements

Regulated-set cements were developed by Greening et al. in 1971 [25] and are highly modified Portland cements that contain from 5–30% of a ternary calcium haloaluminate compound of the form $11CaO•7Al_2O_3•CaX_2$, where X is a halogen (F, Cl, Br or I), generally fluorine. These cements are manufactured by burning, at 1250-1350°C, a homogeneous mixture of limestone, clay, bauxite and fluorite of a composition such that the resultant clinker will contain calcium silicates ($3CaO•SiO_2$, $2CaO•SiO_2$) and iron and fluoride-containing aluminates ($4CaO•Al_2O_3•FeO$ and $11CaO•7Al_2O_3•CaF_2$). Regulated-set cements, known by several trade names including IDEAL RSPC, Reg Set and Jet cement, are not currently manufactured in Canada and sell for ~$300/tonne in North America.

The basic hydration reactions of the silicates present in regulated-set cement are similar to those for Portland cement. However, the hydration of the fluoroaluminate to form ettringite, which is responsible for the rapid setting characteristics, is extremely complex, and is further complicated by the presence of other set-regulating materials required to achieve reasonable working times. The successful use of regulated-set cement depends to a large degree on the control of its setting properties. For this purpose, citric acid and boric acid have been found to be generally useful. Calcium sulphate hemihydrate, which is used to regulate the early set of Portland cement, is unsuitable due to its high sensitivity to temperature, making predictable retardation difficult [21].

Typical regulated-set cements show the following properties [26]:

- short setting times, requiring the use of retarders for workability;
- strengths of 1100-1400 psi within 2-3 hours of placement;
- strength development at temperatures of 5-10°C;
- increasing strength with age, with little or no significant strength loss at later ages;
- low drying shrinkage and good water tightness;
- a significant temperature rise during hydration (~15-20°C higher than for Portland cement).

Examples of the successful use of regulated-set (Jet) cement in Japan, as reported by Uchigawa and Uchida [27], are given in Table 9-4.

TABLE 9-4 USE OF REGULATED-SET CEMENT IN CONSTRUCTION

Building:	At 8-10°C, Jet™ cement was used for construction of columns and walls for the ground floor and first floor slabs of a building; 1-day strengths, at ambient conditions of 6°C, were between 1,800-2,050 psi. The materials was reported to be pumpable, and was cured under canvas sheets.
Highway repair:	The central reservation of a highway was repaired with Jet™ cement produced by a continuous mixer at 5-9°C ambient conditions; 3-day strengths of 2,800-3,530 psi were reported.
Pier foundation:	A new foundation was constructed around an old pier using air-entrained Jet™ cement concrete at ambient temperatures of -3 to -5°C. Two hours after placing the concrete was covered by canvas. A compressive strength of 2,845 psi was attained after 9 hours.
Bridge repair:	A 20 m^2 bridge slab was renewed using Jet™ cement concrete under ambient temperatures of +5 to - 5°C. The concrete was cured with the aid of heaters to attain a five day strength of 3,400-4,700 psi.
Source: ref. [27]	

Calcium Sulphate and Supersulphated Cements

The hydration reactions of calcium sulphates are well known, and, as is discussed elsewhere in this report (see Chapter 8), they are the basis for the gypsum products industry, through the reaction of hemihydrate ($CaSO_4 \cdot 0.5H_2O$) (plaster) with water to form gypsum:

$$CaSO_4 \cdot 0.5H_2O + 3/2H_2O \quad CaSO_4 \cdot 2H_2O$$

The reaction of hemihydrate with water is very fast and setting times, depending on the hemihydrate used, are generally less than 15 minutes. Although good compressive strengths can be obtained with unmodified calcium sulphate plasters, their resistance to moisture is poor. As a result, their use has been confined to indoor applications where they will not come into contact with water.

Calcium Sulphate-Portland Cement Blends

There are many reports and numerous patents (especially from Japan) for rapid-setting compositions based on mixtures of Portland cement and calcium sulphate plasters. Many of these compositions are claimed to set within 2 hours at temperatures down to 0°C [27]. A composition of this type, manufactured by U.S.G. Corporation, is available commercially in North America under the tradename Duracal™.

Supersulphated Cements

"Supersulphated" cement is a term used in the U.K. for a cement made by grinding together 80–85% granulated slag, 10–15% calcium sulphate in the form of dead-burnt gypsum or anhydrite (see Chapter 8), and about 5% Portland cement; the product is ground more finely than is characteristic of Portland cement [29]. The cement has been used extensively in a number of countries and is manufactured to comply with various standards: for example, U.K. (BS 4248:1974), Belgium (NBN 132), France (Norme P.15-313) and Germany (DIN 4210). It is not currently manufactured or covered by standards in Canada.

Supersulphated cement, like high alumina cement, consumes more water on hydration than does Portland cement, the main hydration products being the calcium sulphoaluminate, ettringite, and a hydrated calcium silicate. The cement is resistant to a number of aggressive agents; because of its high sulphate-resistance, the cement has been promoted for use below ground. It has also been used in harbour and breakwater construction on the Belgian coast where performance has been considered good.

Expansive (Sulphoaluminate) Cements

Over the last forty years, several types of expanding hydraulic cements have been developed in an attempt to prevent the shrinkage which is a characteristic of Portland

Figure 9-3 **Placement of magnesium phosphate-based cement concrete at low temperatures. Photo courtesy of Ontario Hydro.**

cement concrete during curing and drying. Another use of an expanding cement which was appreciated later is as a "self-stressing" cement to induce tensile strength in steel reinforcement, that is, to make prestressed concrete, not by the normal method of direct tensioning of the steel, but by inducing this tension through the expansion of the concrete bonded to the steel [29]. Cements of this type represent a significant departure from normal practice, but are now gaining wider acceptance [30,31].

Expansive cement concretes are divided into two categories: "shrinkage compensating," in which expansion, if restrained, induces compressive stresses which approximately offset tensile stresses in the concrete induced by drying; and "self-stressing," in which expansion, if restrained, induces compressive stresses of a high enough magnitude to result in significant compression in the concrete after drying shrinkage has occurred [32].

A general feature of most commercial expansive cements is the production of the calcium sulphoaluminate (ettringite) during the hardening process after setting. Several approaches have been used to generate ettringite during the curing of a cement:

- blending and grinding together high alumina cement and gypsum or anhydrite [29];
- mixing high alumina cement, gypsum and hydrated tetracalcium aluminate [29];
- mixing Portland cement with an expansive agent containing anhydrous calcium sulphoaluminate clinker, ($4CaO•3Al_2O_3•SO_3$), calcium sulphate and lime [33,34];
- blending Portland cement, high alumina cement and calcium sulphate;
- Portland cement manufactured with a large computed C_3A content and calcium sulphate in excess of the usual optimum amount.

The latter three types of expansive cement are recognised in the United States and designated as Type K, Type M and Type S, respectively, reflecting the different alumina-bearing agents. The principal expansive agent in Type K cement, the anhydrous calcium sulphoaluminate, $4CaO•3Al_2O_3•SO_3$, is prepared by clinkering a mix of chalk, bauxite and gypsum at 1300–1400°C [34]. It is this material which reacts with water to produce the ettringite.

Experience gained in the Soviet Union and Japan appears to indicate that expansive cement technology may be best suited to the precast concrete industry, where greater control of the temperature and humidity during the curing process can be achieved [30,31,35]. While there have been several successes in construction and considerable research [30,31], acceptance of the technology in North America has been slow (see further discussion in Chapter 10).

A commercial Type K expansive cement is available under the trade name Chemcomp™ from sources in the U.S.; corresponding expansive agents for use as a cement additives are available as Denka-CSA™, from the DKK Cement Co., and ONODA Expan, from the ONODA Cement Co., both being Japanese companies. Numerous proprietary cement grouts incorporate expansive sulphoaluminate agents of this type.

Magnesia Phosphate and Related Cements

Whereas silicate and aluminate structural networks are formed in Portland cements and high alumina cements, respectively, phosphate-based cement systems generate a structural network of phosphate linkages, generally in association with magnesium oxide rather than calcium oxide. Magnesia-based specialty cements have also been produced with oxychloride and oxysulphate networks.

Phosphate Cements

Phosphate cements were originally reported in the 1940s in the form of two-component systems, generally consisting of a phosphate-containing liquid which was added to a powder comprising calcined magnesite (i.e. magnesium oxide, MgO) and an inert filler, such as silica sand or powdered dolomite. Several other methods have since been used commercially to produce phosphate cements, generalized as follows [21,36,37]:

- reaction of metal oxides (e.g. Al_2O_3) with phosphoric acid at 20–200°C;
- reaction of aluminum acid phosphates with weakly basic or amphoteric oxides (e.g. MgO);
- reaction of siliceous materials with phosphoric acid;
- reaction of metal oxides with ammonium phosphates, magnesium acid phosphates, aluminum acid phosphates and other metal phosphates;
- MgO, dolomite and ammonium phosphate solutions set quickly at ambient temperatures to form a useful repair cement.

In 1974, a single-component cement was developed consisting of MgO and ammonium phosphate ($NH_4H_2PO_4$) in a powder form, requiring only the addition of water to produce a strong, quick-setting binder material [38]. Upon addition of water (~6 % by mass of the dry cement) to the powder, there is a strongly exothermic reaction in which struvite ($MgNH_4PO_4•6H_2O$), the main cementing compound, is formed. Additives such as borax can be used to control the setting time and rate of strength development of the binder.

Cements of this type are of particular interest for repair work by virtue of their extremely rapid setting characteristics. Applications include refractory bricks, mortars, ramming mixes, highway patching, freezer floors, cement pipe, sprayable foam insulation, flame-resistant coatings and patching of preformed concrete products, and placement of transmission line pads at low temperatures (Fig. 9-3).

Most commercial phosphate cements are based on the magnesium ammonium phosphate ("Mag Phos") system under various trade names, including Set-45™ (Master Builders, U.S.), FS-Cement™ (Stauffer Chemicals, U.S.), Horn 240 Concrete™ and FEB-SET-45™ (FEB Services International, U.K.). North American prices exceed $1000/tonne.

Silico-Phosphate Cement

Another interesting development involving a phosphate binder is the so-called "silico-phosphate" cement which has been produced from wollastonite ($CaSiO_3$) powder and buffered phosphoric acid. The phosphate solution consisted typically of H_2O (918 ml), 85% H_3PO_4 (1611 ml), $Zn_3(PO_4)$ (510 g), $AlPO_4$ (456 g) and $Mg_3(PO_4)_2$ (21 g); and rapid-setting concretes were produced using 1 part of the phosphate solution, 1 part magnesia and 4 parts dolomite with setting in less than 30 minutes and strengths of up to 50 MPa within 4 hours [21,39]. There is indication in this binder of a strong interaction between the wollastonite and the phosphate.

Magnesium Oxychloride Cement

Magnesium oxychloride cement, also known as Sorel cement, magnesite cement or plastic magnesia cement, was discovered by Sorel in 1867 [39] and is based on the reaction between magnesium oxide (MgO) and a solution containing magnesium chloride ($MgCl_2$). The binding action is complex and is now thought to be due to the formation of a structural network containing oxychloride compounds of the type $x\text{Mg(OH)}_2 \cdot \text{MgCl}_2 \cdot y\text{H}_2\text{O}$, ($x = 2$ to 9; $y = 5$ to 8) [21].

Sorel cement has many physical properties which are superior to Portland cement: it does not need wet curing, has good fire resistance, low thermal conductivity, good resistance to abrasion, and high flexural and compressive strengths. As well, it develops high early strength and resistance to attack by alkalis, organic solvents, some salts, sulphates, grease, paints and oils [21]. Sorel cement is corrosive to metals such as aluminium and steel and cannot be used in direct contact with them. More widespread use of the cement is largely restricted by its instability to water, limiting it to indoor applications or others free of moisture. Several companies are continuing efforts to improve the water stability of the cement.

The basic cement has been used with a range of aggregates (e.g. sawdust, wood flour, chalk, marble flour, soapstone flour, asbestos powder, sand, ground quartz, stone chips, gravel) and other additives such as bitumen emulsion, $MgSO_4$ and pigments to form a bonded concrete [21]. The cement has been used successfully for many indoor industrial, commercial and domestic floors, particularly for resurfacing old floors and as an underlay for other floor coverings, such as carpet, vinyl and linoleum [41]. It can also be used in insulating and adhesive compositions and for making artificial stone, dental cement, tiles, refractory bricks and paints for plaster and foam concrete walls [42].

The magnesium oxide for Sorel cement is generally formed by the calcination of magnesite at 800–1000°C; however, there are reports that dolomite or dolomitic limestone, containing ~20% MgO, can be used instead of the more expensive magnesite [43]. There are currently no commercial producers of Sorel cement in Canada.

Magnesium Oxysulphate Cement

Magnesium oxysulphate cements are generally prepared by reacting magnesium oxide (MgO) with concentrated aqueous solutions of magnesium sulphate hydrate ($MgSO_4$), in the presence of small amounts of additives such as sodium hexametaphosphate, sodium polyphosphate and soluble phosphate [44]. As is the case for Sorel cements, the binding action is complex and due to the formation of oxy-compounds, this time oxysulphates, of the type $x\text{Mg(OH)}_2 \cdot y\text{MgSO}_4 \cdot z\text{H}_2\text{O}$, ($x = 1$ to 5; $y = 1$ or 2; $z = 3$ to 8) [45].

Magnesium oxysulphate cement has a good cementing action which is somewhat weaker than Sorel cement, although it retains strength better at higher temperatures. It also shares the limitations arising from a poor stability in water [21]. Magnesite is the preferred industrial mineral source of the magnesium oxide required for this cement, although there may be potential for the use of dolomite and dolomitic limestone. Magnesium oxysulphate cement is not produced commercially in Canada.

Other Inorganic Cements

In addition to the foregoing special hydraulic cements, numerous references, too extensive to be considered here, can be found to inorganic cementitious compounds of unusual or unreported composition, which are variously promoted for specialized purposes: for example, rapid-setting repair compounds for concrete, use underwater or underground, use at high/low temperatures, use as grouts for filling cracks and tendon ducts in post-tensioned concrete, and use for water proofing, coating and sealing. Many are proprietary combinations of different cement types and chemical admixtures or other "hybrid" binders comprised of hydraulic cements and organic resins (see Chapter 13). Some examples of the "miscellaneous" materials of this type are given in Table 9-5. More detail can be found in other sources [46-49].

Specialty compounds of this type are of such high added value that they can be transported large distances, often being imported into Canada from abroad or from the United States. This an extremely competitive area which is being

TABLE 9-5 PARTIAL LISTING OF OTHER INORGANIC CEMENT SYSTEMS

Formulation	Description	Ref.
85-parts ultra rapid hardening cement (regulated-set cement), 15-parts high alumina cement, 200-parts sand, 50-parts water, 0.05-parts org. carboxylic acid, 1-part b-naphthalenesulphonic acid-formalin condensate.	1735 psi compressive strength at 1 hour when cured at 5°C	50
Portland cement, high alumina cement, anhydrite and a known accelerator, ground to >4500 cm^2/g	1400, 3000, 5000, 5800, 10700 psi at 1, 2, 4, 6, and 24 hours, respectively	51
50:50 high alumina cement-fly ash	Dry mixed at -9.4°C, gauged with water at 1°C, achieved 1796 psi after 30 hrs curing at -9.4°C	52
Portland cement 54, calcium aluminate cement 25, calcium sulphate 18.8, $NaCO_3$ 2, Na citrate 0.2%	21 MN/m^2 at 24 hrs	53
Pyrament™ (Lone Star Lefarge in U.S.A.)	Rapid strength development, possibly involving alkali-activated supplementary cements	54
Portland cement clinker, dehydrated gypsum, alunite; burned at 500-600°C	Hardens at -10°C	55a
Portland Cement, 20% $CaSO_4$, Ca aluminate clinker	Rapid hardening	55b
Cement clinker with 0.7% Na lignosulphonate, 0.5% NaOH, 4% α-$CaSO_4 \cdot 0.5H_2O$	8, 10, 11, 62 MPa at 10 min., 1 hr, 2 hr and 24 hr, respectively	55c
Freshly burnt MgO mixed with $MgSO_4 \cdot H_2O$ at 600°C, kneaded with water at 11°	Large heat release by MgO hydration and $MgSO_4$ dissolution	56a
MgO 100, $MgCl_2$ 30, and/or $MgSO_4$ 15-100, $Mg_3(PO_4)_2 \cdot 8H_2O$ 5, $Na_2CO_3 \cdot H_2O$ 5 and water 90 parts, cured at 75°	Only 3.2% loss in strength when stored in water 2 months	56b
25 parts water, 25 parts MgO, 5% H_3PO_4, stand to pH~956 parts $MgCl_2 \cdot 6H_2O$ and 75 parts MgO	7% water absorption, 320 MPa bend strength, 8.8 MPa elastic modulus	56c

actively pursued by the Canadian building products industry. In addition to hydraulic cements, this diverse class of building products consumes many of the industrial minerals or mineral products discussed elsewhere in this report: for example, mineral aggregates such as silica, traprock, corundum (Chapter 6); gypsum plasters (Chapter 8); clay products such as bentonite and kaolinite (Chapter 11); glass and mineral fibre (Chapter 12); and mineral fillers, extenders and reinforcements (Chapter 13). Related information on the new development of so-called "geopolymer" cements by chemical modification of clay minerals can be found in Chapter 15.

PROSPECTS FOR INDUSTRIAL MINERALS IN CEMENTS

The wide range of industrial minerals used as raw materials for the production of the hydraulic cements discussed in this section is given in Table 9-6. The potential impacts of anticipated developments in the cement industry on the industrial minerals sector are now summarized. The broader impact of concrete technology will be addressed in Chapter 10.

In general, because the Portland cement producers use raw materials derived almost entirely from their own sources, changes in total cement consumption or in the nature of cement utilization will have little impact on producers of other industrial minerals.

Recent technological developments in the Portland cement manufacturing industry have been concentrated largely on processing methods, usually aimed at reduction of energy consumption in the pyro-processing area where over 80% of production energy is consumed. With the exception of a gradual increase in the rate of strength development and some changes in alkali content, there have not been any major technical changes in Portland cements or in the ways in which minerals are used.

There have been reports of the use of fly ash and bottom ash as a kiln feed material [57], with advantages in terms of reduced energy consumption (by virtue of their glassy nature) and desirable lower alkali contents in the clinker. Other changes reported in Europe [58] have involved the intergrinding of fly ash or slag with clinker to produce "blended cements" (see below). Both developments necessarily reduce the consumption of industrial minerals in the resulting cement.

Some markets for natural pozzolans (e.g. diatomite, chert, tuff, clays, shales) may be available where they are used to bring earth-tone colours to concrete products. Other opportunities may exist to use calcined clays or shales in remote regions of the province where transportation of fly ash or slag is not cost effective.

TABLE 9-6 INDUSTRIAL MINERAL CONSTITUENTS OF CEMENTS

Cement Type	Mineral Raw Materials*
Portland	Limestone, clay, shale, silica, sandstone, gypsum, anhydrite, (iron oxide, fly ash)
Portland-supplementary cementing materials (incl. blended cements)	(Portland cement, slag, fly ash, silica fume), natural pozzolans, incl. diatomite, chert, tuff, clays, shales
Masonry	(Portland cement), lime, high-calcium limestone
High alumina	Limestone, bauxite
Regulated-set	Limestone, clay, bauxite, fluorite
Calcium sulphate/supersulphated	Gypsum, anhydrite, (Portland cement, slag)
Calcium sulphoaluminate	Gypsum, clay, limestone, (high alumina cement, Portland cement)
Magnesia oxy-phosphate, -chloride, and -sulphate	Magnesite, dolomite, dolomitic limestone, wollastonite, (phosphates, magnesium chloride, magnesium sulphate)
Slag-lime	Lime, (slag)

* parentheses indicate other, non-industrial mineral constituents

Because both fly ash and slag are derived from industrial wastes which are in abundant supply in Ontario, neither material presents direct opportunities to the industrial minerals sector, beyond contributing to the wider applicability of concrete from which cement and aggregate producers benefit. There is some indication that the use of fly ash and slag in concrete will permit the more widespread utilization of marginal, alkali-reactive aggregate sources in concrete (see further discussion in Chapter 10).

Silica fume is now recognized as a powerful pozzolanic additive which is of benefit to most areas of concrete construction. In view of the short supply in North America and the demand-driven escalation of prices to over $1250/tonne in North America in the last couple of years, it would appear that an opportunity exists for the industrial minerals industry to supply either an effective substitute or a synthetic product derived from silica to the concrete market.

While not exactly new technology, non-Portland hydraulic cements are considered to have growing importance for specialized construction activities — particularly rapid repair and low temperature work — where their higher cost can be tolerated. At the same time, these materials will provide opportunities for several mineral groups: bauxite and limestone for high alumina cement; fluorite (calcium fluoride) for regulated-set cement; calcium sulphate, limestone and clay minerals for expansive cements; and magnesite and possibly dolomite or dolomitic limestone to provide magnesium oxide for magnesia cements.

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10. Concrete and Cement-Based Products

- Aggregates
- Cement
- Silica
- Traprock
- Pumicite
- Serpentine
- Basalt
- Mica
- Perlite
- Vermiculite
- Wollastonite
- Mineral wool
- Barite
- (Asbestos)

Because of its sheer size and corresponding influence on the market place, the concrete and cement-based products sector is one with considerable potential to influence the consumption of a wide range of industrial minerals.

Concrete is a manufactured composite material that can be described as an artificial stone, similar to natural conglomerates of sedimentary origin (Fig. 10-1). In the broadest sense, a concrete is any conglomerate made of gravel (or crushed rock) and sand bound together with a cement binder (see Chapter 9). Concretes made in this way have been used for as long as cementing materials have been known: early concretes were probably cemented with mud, while later compositions exploited the development of lime, hydraulic lime, Portland cement, and in modern times, plastic resins.

Without doubt, concrete as a construction material is not only the most widely used in terms of sheer volume, but it is also the most versatile, and possibly, the one which has undergone the most change in recent years. In its most visible form, it is the ubiquitous structural concrete which is placed on site for the construction of building frames, bridges, pavement and floors; whereas in the building products field, it is used in a multitude of concrete products, such as bricks, blocks, roofing tile, panels, pipes, etc., which are manufactured in factories (Table 10-1). In addition to these, there are numerous cement-based products containing only fine aggregates, fillers or reinforcing agents which can either be site-placed, such as cementitious fireproofing or insulating concrete, or produced in the factory, as is the case with cement panels.

INDUSTRIAL MINERAL CONTRIBUTION

With the exception of steel for reinforcement and the occasional use of polymers, modern construction concrete is made almost entirely from industrial minerals — namely, hydraulic cements and aggregates from crushed rock, sand and gravel — in proportions which range widely and which are chosen to determine the properties of the final material (Table 10-2).

As discussed in Chapter 9, while Portland cement is by far the principal hydraulic binder used in modern concretes, there has been a strong trend towards the increasing use of supplementary cement materials such as fly ash, slag and silica fume. At the same time, special and non-Portland cement binders are also finding uses for special concretes directed to specific applications, particularly in repair and low-temperature work. Another trend has been towards the use of plastic resins in concrete, either with Portland cement in so-called "polymer-modified" concretes, or alone to form various types of so-called "polymer" concretes, which are used for special applications (see later).

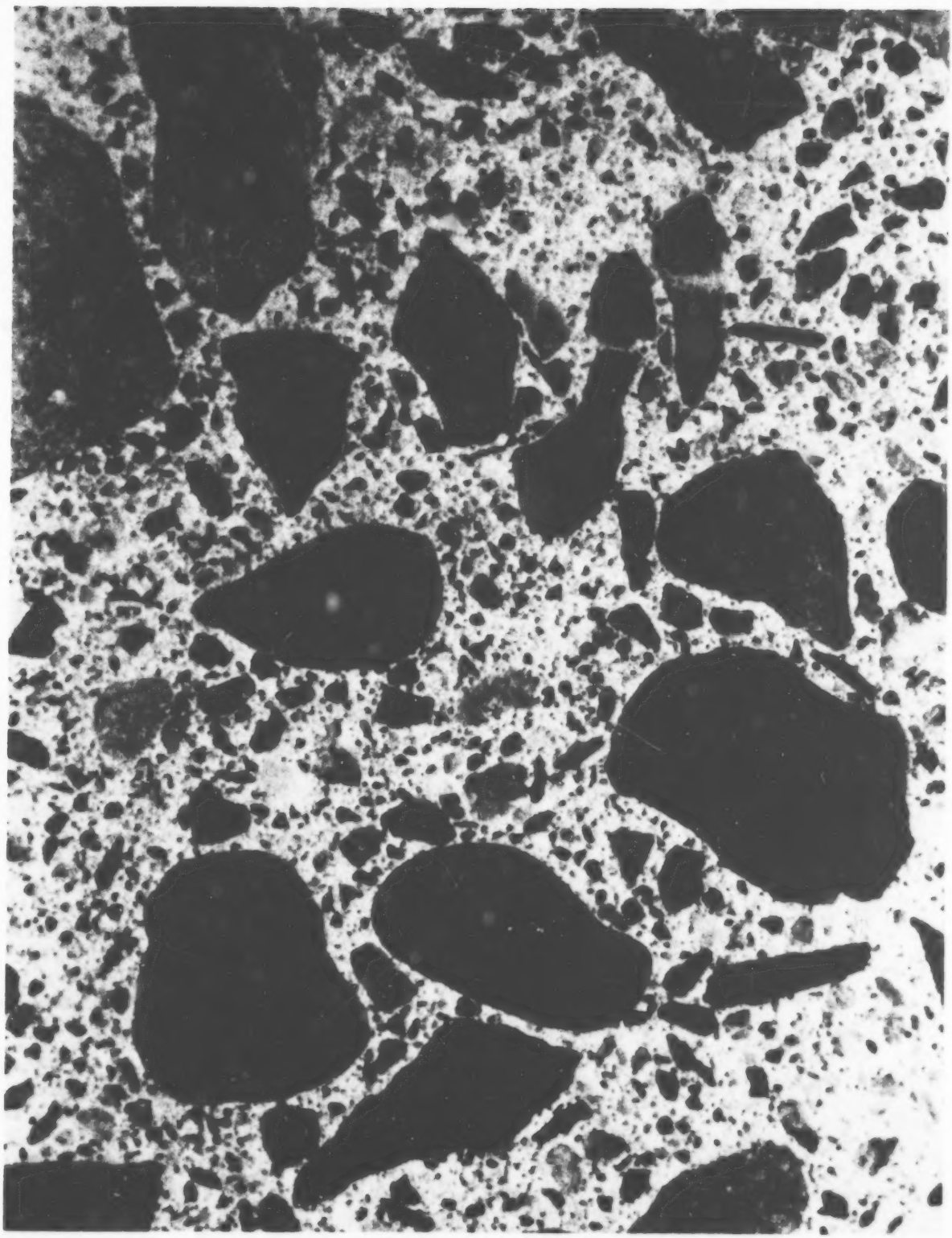


Figure 10-1 **Polished section showing the composite nature of structural concrete. Photo courtesy of Canadian Standards Association.**

Aggregates for construction concrete can be derived from almost any form of gravel, crushed rock or sand that meets the relevant specifications. In Canada, materials for use in structural concrete are subject to specification under CSA Standard CAN3-A23.1-M77 [1]. The factors specified include gradation, presence of deleterious substances and soundness. Local, governmental or architectural specifications may also require other factors to be controlled as needed for the end use. In concrete for special performance applications, high strength or high-density aggregates may be specified by the concrete designer. In addition to natural aggregates, low-density manufactured aggregates such as expanded blast furnace slag or bloated clay or shale (see Chapter 11) are used to produce lightweight concrete. Thus, within limits, concrete consumes a broad range of natural gravels and sands or crushed rock products.

TABLE 10-1 TYPE AND POTENTIAL USE OF CONCRETE PRODUCTS IN DIFFERENT BUILDING FORMS

Function of Concrete / Building Type	Basement/foundation	Floors	Separation walls	Interior cladding	Exterior cladding	Lintels, stairs, etc	Landscaping	Roofing	Core	Frame	Balconies	Exterior walls
	Type of Concrete*											
Low-rise single family dwelling	a,b	c	–	d	e	f	g	i	–	–	–	–
Low-rise multi-family dwelling	a,b	c	a,b	d	e	f	g	–	–	–	–	–
High-rise multi-family dwelling	a	a,c	a,b	d,k	e,h	f	a,g	–	a	a	f	–
Low-rise commercial/ industrial	a	a,c,k	a,b	d	e,h,k	f	g	d	–	–	–	a,b
High-rise commercial/ industrial	a	a,c	a,b	d,k	e,h,k	f	a,g	–	a	a	–	a

* a ready mix
b concrete block
c hollow-core slab
d thin cement panel
e concrete masonry
f precast
g paving brick, slabs, etc.
h architectural panel
i tiles
k polymer

TABLE 10-2 COMPOSITION RANGE FOR TYPICAL CONCRETE

Constituent	% by Volume	% by Mass
Cement	7–15	9–20
Water	15–20	6–9
Fine aggregate (sand)	25–30	28–35
Coarse aggregate (stone)	30–50	35–58
Air	1–8	–

In southern Ontario, a large proportion of coarse aggregates come from crushed dolomitic limestone, whereas in the north of the province igneous rocks prevail. Both are adequate sources for concrete applications provided precautions are taken to assure quality. Because of reactions between the alkalis in Portland cement and some types of aggregates that lead to cracking of concrete in service, limits have been placed on the use of chert, shale, siltstone, sandstone, argillaceous limestones and other potentially reactive components in concrete aggregates. Two general types of damaging alkali-aggregate reactions are recognized: those between alkali and siliceous aggregates (*alkali-silica* reactions); and those between alkalis and components of sedimentary rocks (once termed *alkali-carbonate* reactions)[2]. Both involve essentially similar processes where reactive silica constituents in the component minerals are present, and both require that attention be given to the sources of gravel or crushed stone when concrete is to be made. The recognition of these problems has lead to a general acceptance that stone from certain formations or types of deposit should not be used in concrete.

Structural concrete and concrete products such as pipes, blocks, bricks or tiles are all made from the same basic mineral components — cement, stone and sand. A large number of other products containing a wide variety of industrial minerals are made by binding mixtures of aggregates or other minerals with cement and water. The minerals are selected on the basis of specific properties which they impart to the concrete — for example, density, strength and abrasion resistance, reinforcing value, thermal or acoustic properties, radiation shielding, or fire-proofing value — and include:

- asbestos
- pumicite
- wollastonite
- vermiculite
- serpentine
- traprock
- basalt
- perlite
- mica
- diatomite
- silica
- mineral fibres
- barite

Essentially, any mineral which is not deleterious to the curing properties of the cement used and which brings a practical value to the end-product can be incorporated into a concrete or cement-based product.

THE CONCRETE AND CEMENT-BASED PRODUCTS INDUSTRY IN ONTARIO

Statistics Canada compilations divide the concrete industry into the four categories shown in Table 10-3. Unfortunately, categorizing the industry in this way reflects historical relationships rather than the ways in which the materials are made or used. As a consequence, many manufacturers of the products of interest to this report are placed in the "miscellaneous" category under SIC 3549.

Without consideration to ownership (see later), the structure of the industry is better described in terms of three segments involving different levels of added value in their production, as follows:

- *Ready-mixed concrete*, used to build roads, dams, bridges, foundations and building structural members. Ready-mixed concrete is almost always produced in a batching plant and site-placed.
- *Precast concrete products*, of similar composition to ready-mixed concrete but made in a factory. Precast concrete items range widely from masonry blocks and roofing tiles to highway bridge spans and high-rise columns.
- *Cement-based products*, normally composed of a blend of cement, fine silica, and one or more fillers or reinforcing minerals (see Chapter 13). These products are usually made in a factory, using specialized mixing and forming equipment, and are often subjected to thermal curing (e.g. pressure-pipe, cladding boards, and panel components). Other cement-based products are used for fireproofing structures and are installed at the site by spray-up techniques.

Categorized in this way, the vast majority of structural concrete used in buildings is supplied by the ready-mix producers to be placed at construction sites. The ready-mix manufacturer supplies concrete to meet a specification drawn up by the builder (in house construction) or the concrete design engineer (in high-rise or other major project construction) at a price established by a bid/negotiation process in competition with other suppliers. In this sense, ready-mixed concrete is a *manufactured* commodity.

The industrial mineral components — cement and aggregates — are purchased from a cement producer and an aggregate supplier, respectively; any chemical admixtures or supplementary cementing materials are purchased from suppliers or brokers. Given the vertically integrated structure of the concrete industry (see below and Chapter 9), many of these constituents may come from sources owned by the parent company or company group.

The segment of the industry producing precast concrete products operates in two ways in terms of materials supply. Small companies may purchase ready-mixed concrete on a contract basis and use it in yard or factory-based operations to manufacture precast concrete items such as porch steps, garden paving slabs, lintels and outdoor furniture. Larger operations purchase cement and aggregates in bulk and make concrete in a dedicated mix plant. These companies produce more structurally demanding products such as block, brick, roofing tiles, sewer pipe, manhole units, stairways, balconies and structural beams. At the higher-technology end of the market, companies similarly set up with mixing plants produce bridge spans, high-rise frame units, structural flooring, architectural cladding panels and engineering concrete sections.

Consideration of the data in Table 10-3 suggests that the concrete industry is extensively fragmented due to the presence of many different operating companies. However, with regard to ownership and operation, both the ready-mix and precast concrete segments are closely integrated with the cement manufacturers and the aggregate suppliers. Table 10-4 shows a partial listing of the ownership of companies in the ready-mix and precast concrete industries in relation to the four principal cement manufacturing companies operating in Ontario; in addition to these companies, "Made in Ontario" identifies 22 other companies supplying ready-mixed concrete in the province [4]. Numerous suppliers of precast concrete products are also listed, but it is suspected that most of these supply on a wholesale or retail basis but do not manufacture the products. According to a recent source [5], the four large cement manufacturing corporations control 92% of the ready mixed concrete industry in the Toronto area and much of the concrete products industry elsewhere in the province.

Companies that produce cement board or sprayed-up, cement-based insulation products generally do not belong to the integrated cement and concrete business. In part, because both the cement boards and the insulation products have been developed as substitutes for materials that traditionally contained asbestos, the manufacturers of these products have relationships with other sectors of the building materials industry or are wholly independent. The major international manufacturers of cement boards whose products are imported into Ontario are either associated with the gypsum industry (for example, CGC Inc.), or the asbestos industry (for example, Eternit). In sprayed insulation, companies have frequently entered the field by the development of a proprietary product designed to substitute for the use of asbestos. In some cases, these companies are also involved in the removal of asbestos from existing buildings and its replacement by new, asbestos-free materials. (See further discussion of asbestos-cement materials in Chapter 14.)

DEVELOPMENTS IN CONCRETE MATERIALS AND PLACEMENT

One of the first applications for concrete was in massive structures, and particularly in structures containing or retaining water, such as canals and sea walls. Neither strength nor the rate of hardening were of great consequence, mass being used to provide resistance to mechanical forces both during construction and in service. The sentiment of the times can be seen from the writings of Dobson, a noted British civil engineer, in 1850 [6]:

> "As generally made concrete is nothing more than a weak artificial stone, possessing little strength when exposed to transverse strain, even when the cementing material is thoroughly hard, which... does not take place for many months, if at all..."

In a little over 130 years since Dobson wrote so disparagingly of concrete, a point has been reached where buildings of 90 storeys are constructed with columns, frames, and shear walls made of concrete reinforced with steel. Much of the development in concrete technology has focused on increasing the quantity used to replace steel in such buildings. To do this, both the properties of concrete and the speed with which it could be placed have had to be made competitive with steel-frame procedures. Concrete is now routinely supplied to construction applications with strengths ranging from 70–90 MPa at 28 days.

In the past two decades, concrete technology throughout the world has undergone fundamental changes that have extended both the volume that can be used in construction and the role that it can play in structures. The technological changes have affected all segments of the concrete industry, from ready-mix to the production of sophisticated cement-boards and composites. Research and development has been directed to all three stages of the concrete-making process — mix-design, placement and curing. The major advances have been exploited in the practical areas of material strength, durability and speed of construction or manufacture.

TABLE 10-3 STATISTICS CANADA DATA (1985) ON THE CONCRETE INDUSTRY IN CANADA AND ONTARIO

Category	SIC	No. of Establishments		Value of shipments
		Canada	Ontario	Ontario ($,000)
Ready-mix concrete	3551	584	163	432,313
Concrete pipe	3541	50	11	61,220
Structural concrete products	3542	53	23	101,322
Other concrete products	3549	288	132	222,276

Source: ref. [3]

In practical terms, the revolution in concrete technology has come largely from two interrelated directions: innovations in the materials aspects of cemented systems and innovations in concrete placement techniques. Both of these have, in turn, permitted innovations in the ways in which concrete is used in structures and products and the properties that it exhibits in service. Some examples of the types of developments affecting concrete materials include — selection of aggregates; modifications to the rheology, setting, strength development and durability through use of chemical admixtures; modifications to the binder through use of supplementary cementing materials, polymers and alternative hydraulic cements; strengthening of the cement matrix through use of fibres or other forms of reinforcement; and specialized placement and curing techniques.

It is anticipated that these areas of concrete technology will continue to develop as greater demands are placed on the material by designers and architects and will continue to lead to new opportunities for the use of industrial minerals.

Special Aggregates

An important consequence of the development of high-strength concretes has been a need for specific aggregates. In concrete with compressive strength up to ~70 MPa, good quality aggregate from almost any source can be used. Above this level of strength, it is neccesary to obtain aggregates that are stronger than many of the available crushed limestones, and to meet these requirements, gravels of igneous origin are often required. For high strength concretes over ~100 MPa, crushed basalt and traprock are used; for the ultra higher strength concretes of the future, special aggregates will be required, possibly manufactured from calcined bauxite.

Another aspect of the development of concrete for high-rise structures has been a demand for two distinctly different concretes: high strength concrete and low-density concrete. The frame of a building must support not only its contents, but also the dead-mass of the structure. Thus, the heavier the building structure, the stronger or larger the columns must be. From the point of view of the building owner, the area occupied by columns reduces the rentable space available; therefore by using high-strength concrete, column sizes can be reduced significantly; a further reduction in dead mass can then be obtained by using lightweight concrete for non-structural components, such as floors and interior walls. The trend towards high-strength concrete for high-rise construction has thus produced two opportunities for industrial minerals: a need for both strong aggregates for the high strength concrete and low-density aggregates for the lightweight concrete.

Generally, conventional lightweight aggregates such as pelletized slag or sintered clays and shales have been suitable for normal concrete applications; however, with the advent of higher and higher tower construction and the use

TABLE 10-4 INTEGRATION OF THE MAJOR CEMENT AND CONCRETE COMPANIES IN ONTARIO

Parent Cement Company	Ready-Mixed Concrete	Precast Concrete Products
Lafarge Canada Inc.	McCord Richvale Block & Ready Mix Red-D-Mix Ready Mix Concrete Company	Standard Pressure Pipe Marker Building Materials Concrete Pipe Co. Jiffy Dry Mix Oaks Precast Ind. York Block and Building Supply
St. Marys Cement Co.	CBM (37 plants)	Canadian Building Materials Pre-Con Company Waterloo Concrete Products
St. Lawrence Cement Inc.	Boehmers Dufferin Custom	
Lake Ontario Cement Inc.	KVN Concrete Division Premier Concrete Division	Best Pipe Division Duracon Division Premier Concrete Division Utility Vault Division Primeau Argo Block Co.

Source: ref. [5]

of pumping for the placement of lightweight concrete, new problems have arisen in which the porous aggregates become filled with cement paste during the pumping process, thereby losing their low density. This is expected to create new challenges and opportunites for the manufacturers of lightweight aggregates. (See later discussion of cellular concretes.)

Chemical Admixtures

As a simple mixture of cement, aggregates and water, normal concrete has a somewhat limited range of properties. It may be the ideal material for some uses such as foundations, but its limitations may severely hinder the range of structural applications in which it can be used: for example, in factory-produced concrete products. Reinforcement, prestressing, post-tensioning and thermal curing have all been used to extend the range of applications for concrete, and some of these approaches are of great value in meeting the changing needs of building construction. Other methods have been developed to extend the useful range of concrete applications, based on the incorporation of chemical admixtures.

Admixtures are chemical compounds, added to the concrete in relatively small quantities at the time that it is being prepared. They are now available to influence a wide variety of concrete qualities, although most are used to affect three properties [7-9]:

- air-entrainment, used to render the finished concrete resistant to frost action;
- control of the rate of hardening of concrete;
- control of fluidity, or "water reduction," used to reduce the water-to-cement (w/c) ratio in order to attain rheological and strength benefits in hardened concrete without deleterious effects on the placement process.

Air-entrainment is a process whereby surface active chemicals (surfactants) are incorporated into fresh concrete to encourage the formation of many small air bubbles that remain in the hardened mass after curing. The bubble structure so formed renders the concrete less susceptible to damage by cycles of freezing and thawing during service. Air-entrainment has permitted concrete to be durable in severe climates, such as the Canadian winter.

Acceleration and retardation of the hardening of concrete is an important factor permitting its use in industrialized production or for placing concrete at low or high temperatures. An admixture that increases the early-age strength of concrete is known as an "accelerator;" conversely, an admixture that lengthens setting time and prolongs the period of workability is known as a "set retarder." Accelerators find important uses in permitting early stripping of formwork both in site-placed and precast concrete. A most important area of their use in Ontario has been for cold weather concreting operations. A significant increase in the rate of early strength development at normal or low temperatures enables reduction in the curing and protection periods necessary to achieve specified strengths in concrete.

An interesting variation on the use of set-moderating chemicals is the so-called DELVO™ system from Master Builders Inc. of Cleveland, Ohio. Developed as a means to reduce the wastage of concrete (that presents both a loss of revenue and a disposal cost to the industry), the approach uses a two-component, non-chloride, chemical admixture system that prevents Portland cement, fly ash or granulated slag concretes from setting for periods of time extending over 24 hours [10]. The second component, an activator, when added to the stabilized concrete, overcomes the effect of the protective barrier and allows cement hydration to proceed as normally. The system permits ready-mixed concrete to be transported over great distances if required, or into areas where traffic congestion may cause delivery delays, or to permit concrete to be stabilized for use at a time that precisely suits the construction schedule.

Water reduction permits production of workable concrete at low w/c ratios by decreasing the amount of mixing water required to produce concrete of a desired fluidity. A normal water-reducer is capable of reducing water requirements by about 10–15%. So-called "high-range" water reducers or "superplasticizers" are capable of reducing water requirements by as much as 30%. They were first introduced commercially in Japan and later in Germany, and are now used worldwide. The advantages of using superplasticizers include the ability to produce concrete having high workability for easy placement, sometimes termed "flowing" concrete; or the production of high strength concrete with normal workability at low water content. Pumping or spray-application of concrete is very much facilitated by incorporation of superplasticizers. They have also found successful application for placing concrete in underwater locations. Superplasticizers are widely used by the precast industry to reduce production times and increase productivity. Other important applications include production of concrete with reduced permeability, improved surface finish, reduced shrinkage and overall cost savings. In addition to producing high strength and flowable concretes, superplasticizers can be used advantageously in the production of fly ash, blast furnace slag and silica fume concretes, in the preparation of composites with various types of fibres, and for placing lightweight concrete [8,9,11].

Supplementary Cementing Materials

Modern concrete practice frequently employs one or more of the supplementary cementing materials: natural pozzolans, fly ash, granulated slag, or silica fume (see Chapter 9). Fly ash is used in concrete to substitute for cement and hence reduce concrete costs; to aid in workability and pumpability of concrete; to reduce the temperature rise that occurs when cement hydrates, which can cause damage to fresh concrete; to assist control of alkali-aggregate reactivity; and to give late age strength to high-strength concretes. Granulated blast furnace slag is used to reduce cement costs, reduce temperature rise, and give enhanced durability against attack by some chemical agents such as sulphates and chlorides. Silica fume is used in relatively small quantities to give rapid strength development in high-stength concrete where formwork must be removed at an early age, and to produce concrete of low permeability that is durable to aggressive environments.

As was discussed in Chapter 9, the use of supplementary cementing materials in concrete has an indirect impact on the use of industrial minerals: while significant levels of cement may be replaced in a given mix, they contribute to the wider acceptability of concrete and, hence, the overall consumption of cement. A more direct benefit may be that supplementary cements will permit the utilization of marginal (alkali-reactive) aggregate sources in some regions of the province.

In view of the shortage of silica fume, its escalating value and its importance to modern concrete technology, the authors consider that the development and production of a substitute for silica fume represents a major opportunity to establish a new market for a silica-based product.

Polymer Concretes

As not all cements used in concrete need to be based on Portland compositions, similarly not all concretes require inorganic, mineral-based cements. A substantial body of concrete materials has been developed in which polymers have been employed to totally or partially replace the traditional inorganic cement component. Polymers may be incorporated in concrete in three ways that are recognized by the American Concrete Institute [12,13] (see also incorporation of polymers in gypsum products, Chapter 8):

- *polymer concrete (PC)* — formed by mixing a monomer or resin with aggregate, and polymerizing or curing the resulting concrete after placement;
- *polymer-modified concrete (PMC)* — formed by addition of a polymer or its precursor during mixing of ordinary fresh concrete, with curing initiated after placement; also known as *polymer portland cement concrete (PPCC)* and *polymer cement concrete (PCC)*;
- *polymer impregnated concrete (PIC)* — formed by impregnation of a dried hardened normal concrete with a monomer that is then caused to polymerize in situ.

The major applications for polymers in concrete are to produce artificial stone materials (see Chapters 6 and 13), to obtain a rapidly curing material (usually for precast production or repair work), or to achieve materials that are durable to environments that are otherwise damaging to normal concrete. Typical situations where polymers are used are for concretes that are subjected to acidic or other chemical exposure, or to conditions of highly abrasive wear in pipes or factory floors.

Most of the applications for PIC in North America have involved partial impregnation to give a resistant surface to concrete which is rendered more durable by the process. In 1981, Fowler and Paul [12] reported that approximately 20 concrete bridges throughout the U.S. had been polymer-impregnated, along with an unspecified number of hydraulic structures. Deteriorated concrete buildings have been repaired by monomer impregnation.

Polymer-modified concrete (PMC) has been of considerable interest to concrete users because of the similarity of the mixing process to that already employed for normal concrete. Modification of concrete mixes is usually achieved by the incorporation of latexes, powdered emulsion polymers or water-soluble polymers [13]. Of these latexes, co-polymer systems based on acrylic and vinyl acetates, styrene, vinyl chloride and butadiene have proven very successful. Epoxies are also available that can be added to fresh concrete and will improve the hardened concrete [14]. The chemical resistance attained depends upon the polymer used. Polymer modification produces radically changed properties in concrete while maintaining its traditional appearance. Typical areas of application for PMC are:

- Tile grouts and adhesives
- Concrete repair
- Bonding new concrete to old
- Concrete silo staves
- Bridge deck repair
- Precast panels
- Lightweight cement-based plaster
- Masonry repair
- Water-resistant coatings
- Highway curbs and furniture
- Industrial flooring
- Sewer pipes

The most durable and chemically resistant of the polymer/concrete systems is resin or polymer concrete (PC) produced by using a resin as the total binder for aggregate. A wide range of monomers and aggregates may be used, although care must be taken in the selection of aggregate grading to avoid excessive demand for binder and hence high materials costs. Aggregates for PC should be clean,

sound and have a moisture content of less than 1% to ensure adequate bonding to the polymer. Many monomer systems have been investigated for PC, including polyester-styrene systems, epoxies and methylmethacrylate (MMA), the latter having received most of the commercial attention, especially for repair compounds [12].

Although it was first produced in the 1950s for making synthetic marble, it was not until the mid-1970s that PC became widely known as a repair and construction material. One of the major uses for PC in the U.S. has been in the repair of Portland cement concrete bridges that have been damaged by salt exposure [12]. It was estimated in 1987 that more than 230,000 highway bridges in the U.S. are classified as "structurally and functionally obsolete" with more than 3,000 more being added each year. The repair or replacement costs have been estimated at $62.8-billion [15]. Similar types of salt damage are a feature of many parking structures and garages in buildings in Ontario where potential applications for PC in the form of overlays or screeds are considerable. Floors in industrial buildings, especially chemical factories and those exposed to dairy and animal wastes or where excessive abrasion is experienced, such as in warehouses, have frequently been made from or overlaid with PC. In some cases, a demand exists for special aggregates for such applications, including hard aggregates for abrasion resistance. A recent article by Nutt [16] suggests that a major new market for PC lies in the area of precast concrete products (see later discussion).

Compared to countries like Britain, West Germany and Japan, which have developed technical expertise in the use of polymer concretes for over 20 years, this area does not seem to be very well known or to have received much attention in Canada, with the exception of Quebec. During the last decade, Quebec companies like Plastibeton Inc., Francon and Janin Construction have been producing the material commercially for construction projects in Canada and abroad. In view of their importance as repair materials, polymer concretes, in all their forms, are expected to be of major importance in the future repair and restoration of Canada's aging and deteriorating highways, bridges and civil infrastructure, an activity which Statistics Canada currently estimates at $100-million annually [17].

The growth of the market for polymer concretes is part of the trend towards greater acceptance of plastics by the construction industry. The potential impact of increased use of polymer concretes on industrial minerals will be towards the development of additional opportunities to supply special aggregates and fillers: for example, aggregates such as granite, marble chips and siliceous stone at loadings of 60–66%; and fillers such as kaolin, ground calcium carbonate, wollastonite, barite, titanium dioxide and silica flour at loading levels in the range 2–15%. Further discussion of fillers, plastics and other polymeric materials in construction can be found in Chapter 13.

Non-Portland Cement Concretes

In the same way that Portland cement can be replaced by organic resins in polymer concretes, it can also be replaced by other mineral-based hydraulic binders (e.g. high alumina, regulated-set, calcium sulphate, sulphoaluminate and magnesia cements) to give a range of specialized concreting materials which are gaining prominence for specialized construction and repair work.

Many of these non-Portland cement concretes have characteristics which are quite different from Portland cement concretes — for example, significant heat generation during hydration of the binder, and rapid development of compressive strength — which make them ideal for specialized applications in construction and building maintenance. Examples of their applications include concrete patching and other repair work, where the rapid-setting characteristic can enable a damaged structure to be returned rapidly to commission; and concrete placement at low temperatures, especially in remote locations away from sources of power for heating during construction.

Beyond the normal restrictions placed on Portland concrete aggregates (e.g. physical soundness and gradation), little information has been found on the requirements for the aggregates in non-Portland cement concretes. In view of the lower alkalinity of the binders, it is possible that some of the more marginal classes of alkali-reactive aggregates found in some regions of the province may be suitable.

Further information on the consumption of industrial minerals by the special cements used in these concretes can be found in Chapter 9.

Fibres and Other Reinforcements

Fibre reinforcement has always played an important role in the toughening of building materials, and can be traced to the early use of straw in brickmaking by the Egyptians and the use of animal hair to reinforce plaster by the Romans. The basic requirements of an engineering material are flexibility, tensile strength and toughness. While normal concrete has adequate compressive strength and stiffness for structural use, it is brittle and has poor tensile and impact strength — weaknesses which have traditionally been overcome by steel reinforcement or prestressing. The use of small-size fibre reinforcement in cement serves to improve the fracture toughness, tensile and flexural strengths, and resistance to fatigue, thermal shock and spalling. Improvements of this type lead to economic savings and performance gains by permitting the design of building elements of reduced dimensions with increased flexural and impact strengths [18-20].

Modern developments in the use of fibre reinforced concrete began in the 1960s and continue today with innovations in the use of fibres ranging from high modulus types such as steel, glass, asbestos, carbon, Kevlar etc., which generally improve strength and stiffness, to low modulus high-elongation fibres such as nylon, polypropylene and polyethylene which have large energy absorption characteristics and impart mainly toughness and resistance to impact (Table 10-5).

The use of fibre reinforcement by the industry has evolved along two basically separate paths—namely, bulk ready-mix and precast concrete and thin sheet cement or mortar products—each with its own requirements. Currently, steel and polypropylene are the principal reinforcing fibres used in bulk concrete materials, and glass and cellulose are now being used to replace asbestos in board products (further information on this latter group is given later in Chapter 14).

In bulk concrete, the challenge for fibre manufacturers has been to combine good durability with all the desirable physical characteristics that make it generally acceptable for every application. Polypropylene is now widely used and cost-effective, particularly for slabs where it is effective in controlling plastic and temperature-induced shrinkage cracking; however, its weaknesses are that the low modulus of the fibre does not allow significant stiffening of the concrete, poor workability and finishing, and combustibility. By comparison, steel provides good reinforcing characteristics but has a tendency to corrode and must be used with care wherever salt exposure can occur. In a similar way, low-alkali borosilicate fibres such as E-glass introduce good stiffness and flexural strength but deterioration can occur in under ten years in the highly alkaline (pH 12.5–13.5) environment of cement, causing loss of initial strength and toughness [19]. Special alkali-resistant glass formulations, such as zirconia-containing (AR) glasses, or polymer coatings, have been examined in an attempt to counter this effect, but long-term durability remains to be demonstrated [18-20]. Pioneering work on glass-reinforced cement (GFRC) and the durability of glass fibres in cement has been carried out by the Building Research Establishment in the U.K. [20]. Commercial glass fibres are available under many tradenames including AR-Glass and Cem-FIL (alkali-resistant) in the U.K. and U.S.A., Forton-PGRC™ (polymer-coated) from Holland, and other formulations by groups in the U.S.A. and Japan.

TABLE 10-5 TYPICAL FIBRES USED IN CEMENT AND CONCRETE MATERIALS

Fibre Type	Typical Applications
Glass	Precast panels, curtain wall facings, sewer pipes, thin concrete shell roofs, wall plaster for concrete block
Steel	Precast concrete roofing units, pavement overlays, bridge decks, refractories, concrete pipes, airport runways, pressure vessels, blast-resistant structures, machine foundations, marine structures, tunnel linings, floor slabs, shore and slope stabilization, shotcrete
Polypropylene, nylon	Foundation piles, prestressed piles, facing panels, flotation units for walkways and moorings in marinas, road patching material, heavyweight coatings for underwater pipes, concrete precast elements, floor slabs
Asbestos	Sheet, pipe, boards, fireproofing and insulating materials, sewer pipes, corrugated and flat roofing sheets, wall linings
Carbon/Kevlar	Corrugated units for floor construction, single and double curvature membrane structures, boat hulls, scaffold boards, lightweight cladding panels
Mica flakes	Partial replacement for asbestos in cement boards, concrete pipes; repair materials
Mineral wool	Spray-applied fireproofing
Wood/cellulose/ vegetable fibre	Sound absorption panels for highways, building boards, low-cost roofing materials and facing panels

Source: adapted from refs. [18-20]

An exciting new development is the commercialization of carbon fibre reinforced concrete (CFRC) by Kajima Corporation and Sumitomo Metal Industries in Japan. Successful use of CFRC is reported in many building applications including autoclaved lightweight precast concrete panels and curtain walls where the carbon fibres have excellent durability and confer high tensile strength, bending strength, coupled with low shrinkage. A key factor in the viability of this new Japanese technology has been the reduction in costs for the production of acceptable carbon fibres from a pitch-based process [21].

This is an active area of research and development worldwide, particularly in the U.K., the U.S.A., Western Europe and Japan, and new fibres or methods of fabrication are continually being introduced. At the present time, CFRC seems to offer good potential as the basis of high-performance building elements in the future. The impact on industrial minerals of these and future developments in fibre-reinforced concrete are considered to be towards the demand for higher performance cements and aggregates as the level of technology in the products increases.

Further discussion of the use of fibres in cement-based materials can be found later and in Chapter 14.

Placement and Curing

The techniques used for placement and curing play a critical role in modern concrete technology, both on-site and in the factory. While the air content and w/c ratio determine the void structure in the binder component of concrete, the efficiency and care taken during placement determine overall void volume. A well-designed concrete mix, which is poorly placed or incompletely compacted may not reach the required strength, and will undoubtedly have poor durability in service. The placement method used for concrete depends largely on the type of structure being built and the part of the structure under construction. While being less recognizable, modern concreting techniques are placing increasing demands on the use of industrial minerals.

Floors and basements are usually poured into forms set in an excavated foundation, using semi-fluid concrete of relatively low strength. In some cases, a flowing concrete will be supplied to produce a so-called "self-levelling" floor. Support columns and floors in high-rise buildings are usually placed by pumping concrete into form work that contains substantial reinforcing steel. The concrete will be designed to give both strength and fluidity. As noted earlier, when concrete is to be pumped, particularly to high levels, more control is required over the shape, size gradation, density and absorptivity of aggregates beyond that normal for other ready-mix concrete. Apart from the incorporation of lightweight aggregates (see Chapters 6 and 11) in the mix to reduce density and dead load in floors for high rise structures, recent developments in the controlled use of foamed concrete (see later) for the same purpose will place new restrictions and demands on aggregates and binders alike.

Another approach to site placement is the so-called "shotcrete" procedure, in which fluid concrete is sprayed onto a surface or a reinforcing framework to produce either a surface finish or a shell-like structure. This method is also gaining prominence for rapid repair work of structures where normal placement techniques would be difficult (e.g. marine locations or underground). Developments here have been towards advanced binding agents incorcorating silica fume and chemical rheological aids and the use of reinforcing fibres, Canada being at the forefront of the new technology. One of the most interesting buildings formed by shotcreting is a grandstand at a camel racetrack in Dubai where a traditional tent-like form was developed by spraying concrete onto a frame.

Factory-made (precast) concrete is either placed in forms similar to those used for site-work, or made with a minimum water content to produce a consistency that permits it to be press-moulded or extruded. An intermediate form of concrete placement, between site-casting and precasting, termed "tilt-up" constuction, has been introduced. Using this method, wall or panel units are cast horizontally in forms at the construction site and then raised (tilted) into position to form structural elements. The procedure is said to have gained great popularity in both Atlantic and Prairie regions but, as yet, has not been developed in Ontario. Cement products, particularly fibre-reinforced products, are made on production-line machines similar to the systems used for producing gypsum wallboard (see Chapter 8) or other board products.

The curing, or hardening, of concrete involves a complex series of chemical reactions between water and cement that may continue throughout many years in service. So that construction can proceed at a reasonable pace, or so that precast concrete units can be commissioned, concrete must be designed to reach a required strength after a short time period (up to 3 days for site-placed concrete) to permit removal of formwork. For concrete products made in a factory, dry (zero-slump) mixes, high compression molding, chemical curing aids and thermal curing are now all employed to minimize production times. Similar factory practices have been used with some site-placed concrete, to permit forms to be removed at less than 3 days and concrete construction to proceed at a much increased pace. For example, the concrete used in the Scotia Plaza building in Toronto used a combination of chemical admixtures, silica fume and slag cement in the design of a high-strength concrete from which the forms could be removed after 11 hours [22]. The significance of this development is put into perspective when it is noted that many precast concrete

factory production cycles require up to 12 hours before forms can be removed and the concrete moved to the thermal curing process.

In general, as on-site and factory concreting techniques become increasingly advanced, more and more emphasis will be placed on the materials of construction and the use of chemical agents to control the fluidity, w/c ratio, rate of setting and durability of the concrete. In turn, these trends will continue to place increasing demands on the industrial minerals suppliers and the building products industry for higher quality and special materials.

DEVELOPMENTS IN FACTORY-MADE CONCRETE PRODUCTS

The relative simplicity of making concrete mixes, the variety of forms that concrete can take, and the gradual development of cements, admixtures and processes that can be applied to cement-based products have made it an ideal material for factory fabrication. The result has been the development of two parallel industries: precast concrete manufacturing and the production of reinforced cement products.

Some concrete products lend themselves readily to factory production. Notable examples are blocks, bricks, roofing tiles and pipes — none of which could be made by site placement of concrete in an efficient way, and all of which are substitutes for factory-made clay products. Other products have been designed to take on the function of steel, masonry or site-placed concrete. Typical examples are cladding panels, flooring and building frame members. The use of precast concrete rather than site-placed material has a number of advantages, the most important of which are savings in construction time, the ability to continue construction when weather conditions would preclude site casting of concrete, and the elimination of scaffolding and form work. These are typical of the advantages that factory-construction brings to building across all types of materials. In general, precast concrete has been the most successful of all the types of factory-based construction in North America.

For the producer of industrial minerals, the interest in precast concrete and factory made products lies both in the growth of use of concrete that results, and in the opportunities that may be developed to introduce new minerals into cemented systems. It is not possible to examine all of the aspects of precast concrete and cement-based products in this report; in the following paragraphs a number of examples relevant to the use of industrial minerals are considered from the many applications currently practiced. The topics selected for discussion as illustrations of the scope of factory-made concrete are: precast concrete building frames, bricks, blocks, tiles and concrete pipes, precast architectural panels and thin cement panels (boards).

Precast Concrete Building Frames and Flooring

Reinforced concrete is being used increasingly in the frames of buildings to replace, in part or in total, the structural steelwork. In most cases, frame members are constructed using site-cured concrete, although modern forming methods have resulted in rates of production that almost reach factory conditions. One of the advantages that steel frame construction has over site-poured concrete is that the entire structural frame can be pre-fabricated in parts at a factory, brought to the site as required to meet building schedules, and erected. It is natural that at some point precast concrete frames would be recognized as having many of the construction advantages of steel.

In 1973, the first North American H-frame structure built from precast concrete was erected in Calgary, Alberta, for the grandstand at Stampede Park [23]. Similar structures are now common, and renewed interest in the technique has been developing in North America and Europe where two types of structure are commonly built:

- Large-span frames with double-tee floors (also made from precast concrete) suitable for use with parking decks and low-rise commercial buildings. A recent example is the Harbourfront parking garage in Toronto.
- Short-span frames with precast hollow-core floors (see below) for use in office and commercial buildings.

A further development in precast framing is the integration of cladding such as brick panels, natural stone and lightweight precast architectural panels. Also, precast elevator and stair towers will be incorporated in high buildings in the near future [24].

Closely related to the use of precast concrete as framing is the production of hollow core floor slabs. In office and commercial structures, these are frequently integrated into the concrete-frame system. Similar slabs have been used for single-family housing construction, where they are placed on load-bearing masonry to replace the more traditional lumber flooring. The slabs are then grouted with a cement topping to produce a monolithic floor. The slabs are used to provide two advantages: (a) rapid construction, and (b) contribution to energy efficiency. Considerable labour saving is found in construction of floors using hollow core slabs. For example, two carpenters take one week to build a wood joist floor system while concrete floors can be installed at a rate of 8-10 homes per day [25]. Used as heating ducts, another advantage of hollow core floors is that the concrete acts as a passive thermal storage device offering substantial heat efficiency [26].

In principle, the use of factory-made hollow core floors for low-rise single-family houses appears ideal; however, in practice, problems were encountered and the practice was not established. The major problem, particularly experi-

enced on a project in Westney Heights, Ajax, was found to be the difficulty in getting exact dimensional matching between the factory-made floor slabs and the hand-placed masonry foundations. Reworking or cutting slabs resulted in reduced construction efficiency, and the practice appears to have been discontinued [27]. This is a clear illustration of the difficulties experienced in combining factory-fabricated units with site-placed construction elements.

Precast Concrete Bricks, Blocks, Roofing Tiles and Pipes

Concrete blocks used for foundations and walls have been available for many years. Recently, other small precast concrete units have become available in the form of bricks and tiles. This group of products, as well as with concrete pipes, can only be made conveniently in the factory. Until recently, they were largely supplied by the clay products industry (Chapter 11). Some time ago, concrete pipes started to replace the clay products; now bricks made from concrete are making substantial inroads into the masonry market [28]. With good durability and aesthetic appeal that is difficult to distinguish from clay brick, these products are generally cheaper than clay masonry. In Ontario, facing or calcite bricks, reconstituted stone, imitation or cast stone detailing, and interlocking retaining wall blocks are now all available from local producers.

In Europe, precast products based on brick and paving block have extended into a broader range of applications. Typical products are interlocking coping units for finishing free-standing walls, and a slotted drainage system designed to be integrated with a block paved, asphalt or laid concrete surface. One European manufacturer has introduced a concrete product into the engineering brick market, a unit previously only produced by the clay brick industry. While, for reasons of climate or traditional building style, such

Figure 10-2 Concrete roofing tiles. Photo courtesy of Marley Roof Tiles Canada Ltd.

products may not be suited to the Ontario market, they serve to illustrate the imaginative ways in which relatively simple precast concrete products are being used.

A challenge, similar to that for the brick market, has been made in the area of roofing products through the introduction of concrete roofing tiles in Ontario. Although clay tiles have not been successful in displacing shingles in Canada, one manufacturer has introduced production methods for concrete tile from Europe into the province. In 1982, Marley Roof Tile Canada Limited began operations in Milton, Ontario. In late 1988, Construction Canada [29] reported that in the six years that these products had been available the equivalent of 41,000 homes had been tiled with them. However, they still remain a luxury roofing material that is more expensive in terms of original installed cost than most other common roof-cladding materials. The main focus of the marketing of these products has been on durability with a guarantee of service of 50 years. Sawchuck [30] has compared a number of roofing materials from various cost, performance and aesthetic perspectives with the results shown in Table 10-6.

Concrete roofing tiles are made by an extrusion process from Portland cement, graded fine aggregate and oxide pigments that give shades of red, brown or grey. The tiles are usually designed to be interlocking and overlapping to prevent moisture movement into the sub-roof structure (Fig. 10-2). Resistance to freezing and thawing is introduced through the high density to which the mix is pressed during extrusion.

Another major market for precast concrete is in pipe products. Although they are mostly used in civil works, pipes for storm and septic sewer installations are intimately connected to building construction, being part of the process of servicing land for new development. As is discussed in Chapter 11, until the late 1970s a major portion of the service pipes in Ontario were made from clay products. Subsequently, plastic and concrete pipes have largely taken over this market.

Precast concrete pipes include three types of products: pipes, box culverts and manholes, all of which are used for installation of both storm and septic sewer lines. According to the Ontario Concrete Pipe Association, ~55% of the concrete pipe made in Canada is produced in Ontario [31]. However, data on the provincial industry relating to the number of companies and the total value of production are not available. Based on the Statistics Canada data for 1985 (Table 10-2), a market of $30-35 million is estimated for the eleven active companies. Regulation of the concrete pipe industry through standards and an Environment Prequalification Program set by the Ministry of the Environment has led the industry in Ontario to upgrade production facilities to world-class standards, claimed to be the most advanced in North America [31].

Concrete pipe and related products are produced from a low water-content (zero-slump) concrete that is reinforced with a wire cage. Modern, automated equipment from Europe or the United States is used to vibrate and compact the concrete into tubular molds or forms (Fig. 10-3). From a materials perspective, the concrete used for pipes must meet industry specifications for quality and durability. Sanitary sewers are expensive to install and are expected to have a service life up to 100 years [32]. A considerable proportion of the industry now uses blast furnace slag cement to produce concrete with low permeability and resistance to the acidic, corrosive environment of drainage systems. An industry spokesman considered the introduction of slag cement as the principal materials-related innovation over the past 10-12 years [31].

In small diameters (6–10 inch), plastic pipe has become well established in the market, in particular as a replacement for the asbestos-cement products previously used. Made from PVC, it is heavily filled with limestone extender (see Chapter 13). Experience in Europe with PVC pipe has reported it to be unsatisfactory in service, and in Denmark and Germany, a return to clay products has followed. Elsewhere, concrete pipe is being produced in the 6–10 inch dimensions. Bartley [31] suggested that this could be a new

TABLE 10-6 COMPARISON OF ROOFING MATERIALS

Material	$/sq. ft. (Installed)	Avg. Life (years)	Warranty (years)	Colours	Weight (lb/sq. ft.)
Asphalt shingles	0.75–1.00	10–25	10–25	Wide selection	2.1–>3
Cedar shingles	3.25–3.50	30	30	Natural	2–2.5
Cedar shakes	3.25–3.50	30	30	Natural	2–2.5
Marley roof tiles	5.50	50+	50	Wide selection	10
Clay tiles	6.50–7.50	50+	50	Wide selection	10
Copper	5.00–6.00	30	30	Copper	2.4
Slate roof tiles	11.00–12.00	50+	1*	Slate grey or black	11

Source: ref. 30; * installation

direction for Ontario producers, although at the present time, lack of plant capacity appears to be constraining moves in this direction.

Although more an issue related to civil works, the use of aggregate for bedding pipe is an important outlet for low-value industrial minerals. Aggregates for this purpose are specified through Ontario Ministry of Transport — Provincial Standards, Section 800. Of interest to industrial mineral producers is the fact that the Ontario Concrete Pipe Association is promoting the use of better quality granular aggregate to improve service life of sewer systems [31].

Concrete box-culverts are an integral part of drainage systems; they can be cast in place or they can be fabricated from precast sections. The use of precast box sections is an illustrative case of the value of the industrialization of construction processes in permitting construction at greater speed than site-casting will allow. An example of the advantage of using factory-made units was the installation of a 1500-mm diameter drainage system across a major highway in Mississauga. By using precast box culverts, the installation was completed on a weekend and thus avoided a costly road detour that would have been required to permit conventional poured concrete construction [33].

Precast Architectural Panels

Precast architectural cladding is a major facet of factory construction using concrete. Large volumes of panelling are used in commercial and industrial construction throughout the province.

Precast concrete cladding has been developed over the past fifty years with many changes reflecting differences in architectural styles. The most common cladding until recently has been the washed, exposed aggregate finish that permitted the use of decorative crushed stone or gravel aggregates. According to a recent review of the industry in Europe [34], this trend has now given way to the use of precast concrete panels faced with brick (see Chapter 11), and natural and reconstituted stone (see Chapter 6).

Architectural panels offer a number of opportunities to the industrial minerals producer through consumption of bulk aggregate and cement, and use of high quality, aesthetic finishing products such as crushed quartz and other decorative minerals, or thin granite panels.

Thin Cement Panels and Boards

An area that has been identified as growing rapidly among concrete products is that of thin precast concrete panels [35]. The panels are made of concrete reinforced with a variety of materials including woven, vinyl-coated glass mesh, or alkali-resistant glass mesh. Many of the products are of relatively low density (typically 17 kg/m^2) as a consequence of using lightweight aggregates such as expanded shale. Though similar to gypsum wallboard in their form and mode of application, thin panels are designed to be highly water-resistant. Functionally, two types of product are available in North America: an exterior cement board and a so-called "tile backer" board. Both products can be manufactured by continuous processes that employ a Portland cement-aggregate slurry with appropriate reinforcing materials.

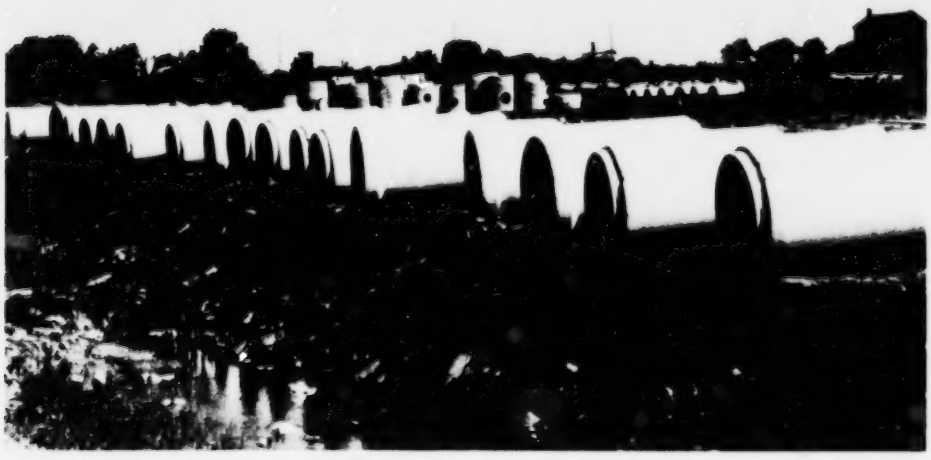


Figure 10-3 Concrete sewer pipe. Photo courtesy of MATEX Consultants Inc.

For exterior applications thin cement panels are used as the base of ceramic tile or thin-brick (see Chapter 11) panel systems. The cement panels can be also coated with stone aggregate bound in an epoxy matrix or an acrylic polymer-based elastomer to produce a stucco-look finish. For interior surfaces, gypsum drywall, veneer plaster or ceramic tiles are applied (Fig. 10-4).

A major interior use for this type of product is as a water-resistant tile base for tub and shower areas or as an underlay on floors or countertops [36]. The growth of the market for such materials is in part a result of a change in the National Building Code (1985 Edition) that requires that ceramic and plastic tile installed on walls around bathtubs or showers shall be applied over moisture resistant backing (Sec. 9.30.13.4). This change will affect most new homes.

The growth in these products has been such that in 1986 only two companies were manufacturing in Canada; by 1988 ten were said to be in the market [35]. At least four products are being imported from the U.S., Mexico and Europe [37]. A committee of the Canadian Standards Association has recently been formed to develop standards for the panels [38].

Related cement board products which are manufactured with fibre reinforcement and, for the most part, without coarse aggregates are discussed below.

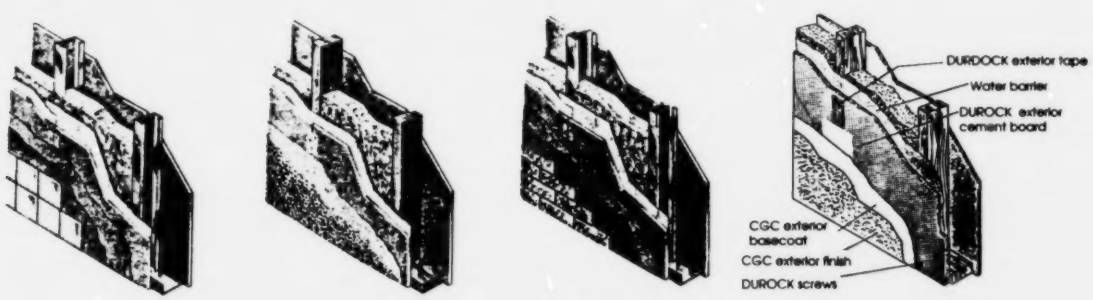
DEVELOPMENTS IN CEMENT-BASED PRODUCTS

While the concrete industry is dominated by the ready-mix and precast concrete producers, an important remaining segment of the industry is concerned with more specialized products and applications which are still based on the use of hydraulic cements but which, for the most part, do not contain the conventional stone and gravel aggregate materials found in concrete. For the historical reasons noted earlier, this segment of the building products industry is more closely affiliated with construction chemicals and specialty products companies, rather than being integrated with the major cement organizations.

Like concrete, cement-based products can be manufactured in factories, as with fibre-reinforced cement boards, foamed cement and wood fibre-cement blocks and panels, or site-placed, as is the case with cement grouts, spray-applied fireproofing and insulation. Opportunities in this sector can be related to restrictions which are now placed on the use of asbestos and asbestos products, notable examples being asbestos-cement board and pipe products, and the corresponding need for effective replacement materials. Discussion of the important area of asbestos replacement materials (of which fibre-reinforced cement products are an important component) and information on recent developments in a new class of cement-based products termed "new inorganic materials" can be found in Chapters 14 and 15, respectively.

Cement Grouts

Cement grouts are fluid mixtures of cement, sand and water which generally incorporate chemical admixtures to promote fluidity, reduce water content and prevent shrinkage. They are used routinely for the sealing and repair of cracked concrete, for anchoring structural members, and for filling the void surrounding the steel tendons in post-tensioned concrete. In the latter type of application, they



ceramic tile exterior over steel stud | exposed aggregate over wood stud | thin brick over steel stud | elastomeric texture coating over wood stud

Figure 10-4 **Examples of different installations of thin cement using tile, exposed aggregate, thin brick and an elastomeric texture coating. Courtesy of CGC Inc., Durock Cement Board product literature.**

serve both to protect the prestressing steel from deterioration due to the influences of corrosion during service, and in some instances, to provide a bond between the steel and the concrete members to distribute the load.

While modern grouts have various properties depending on the application, many share the following general characteristics: for example, minimum w/c ratios to provide high strength and low permeability; low viscosity to permit pumping without bleeding or segregation; non-shrinking in the plastic state or on hardening; predictable setting and hardening properties; and freedom from chemicals which might be aggressive to the steel or concrete

Grouts have undergone considerable development in the last few years, in keeping with progress in other areas of cement and concrete technology. Numerous specialty grouts are now available in the North American market, most of which are highly developed materials which are generally sold by construction chemical companies as proprietary premixed formulations ready for use on site. They are expected to continue as an important segment of the building materials field. Recent developments have included the use of silica fume, superplasticizers, water-retentive admixtures and expansive agents.

Cellular Concretes

Although precast cellular (foamed) concrete masonry products are popular in Europe as a construction material, they have been slow to be accepted in North Anerica. An alternative approach is taken by the recently announced "Celcon™ Cellular Concrete System" developed in Canada by Anthes Equipment, Ontario, for on-site placement of concrete. This system (Fig. 10-5) incorporates a proprietary foaming technique which produces concrete in a range of controlled low densities and is being promoted for low-density flooring for high-rise construction, an application which, as noted earlier, is problematic for conventional lightweight aggregate concretes [39]. Early reports are that the foaming system allows a consistency of product which overcomes many of the problems previously encountered with cellular concretes [40].

Wood-Fibre Cement Products

The patent literature reveals numerous approaches to the use wood fibres or chips in building products using cement binders (see also wood fibre-gypsum products in Chapter 8). Products of this type are of interest wherever there are plentiful sources of wood processing wastes. They have been of particular importance in third-world countries as a source of economical building materials where local woods and natural fibres can be used (e.g. sugarcane bagasse, jute, sisal, bamboo, etc.). There are two basic problems in the production of wood fibre-cement products: overcoming the tendency for the sugars in the wood to retard the hydration and setting of the cement and long-term durability as a result of degradation of the wood. Traditional approaches have

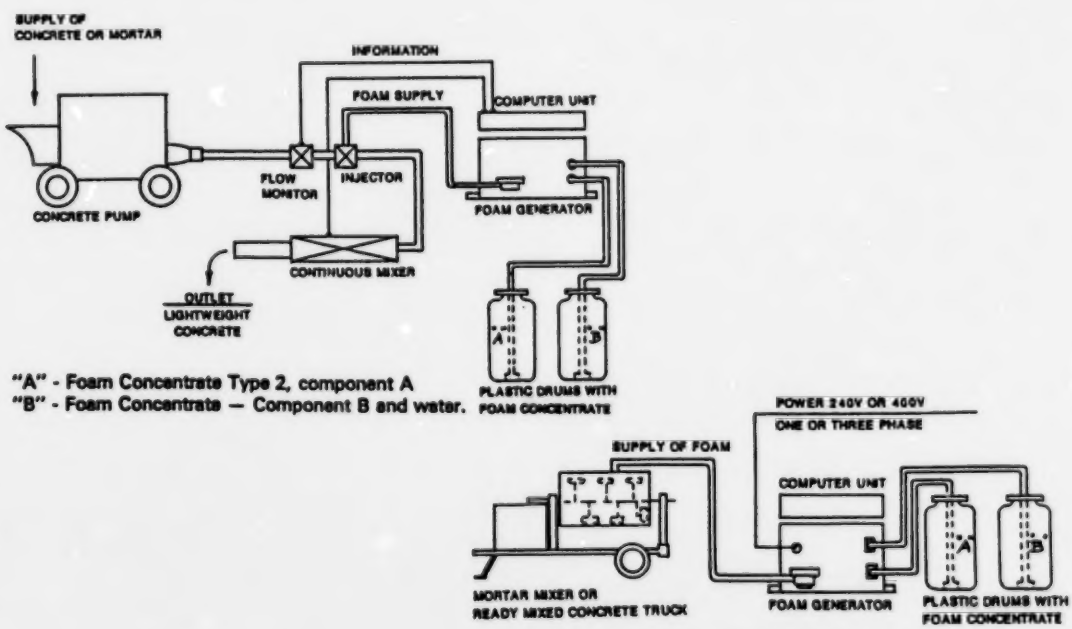


FIGURE 10-5 SCHEMATIC OF ANTHES CELCON™ CELLULAR CONCRETE SYSTEM. COURTESY OF ANTHES EQUIPMENT.

involved chemical treatment (so-called "mineralization") of the wood to render the sugars inactive and to stabilize the wood against decay [41].

The major commercial application of wood-fibre cement technology in Canada and the US has been for precast sound absorptive panels on highways. These products, which are marketed in Canada as Durisol™ by Durisol Materials Ltd. of Mitchell, Ontario, can be backed with normal concrete and have proven to be very durable under the severe exposure conditions (e.g. freezing and thawing, direct sunlight and salt spray) encountered on highways. Durisol also promotes a range of precast block products for use in building systems [42].

With the nation's plentiful supply of wood by-products, wood fibre-cement technology would seem to have significant potential for further exploitation in Canada for the manufacture of low cost building materials suited to extreme exposure conditions.

PROSPECTS FOR INDUSTRIAL MINERALS

Overall, it is clear that concrete and cement-based products are at the vanguard of modern construction materials technology. They are an example of a group of materials which have undergone constant evolution in terms of versatility, durability and performance — making them ideally suited to the demands of advanced building practices and factory production. In this way, they are already an active part of the trend towards industrialized construction while at the same time satisfying the other current needs of the industry in terms of repair, renovation and consumer health and safety. They are composed almost entirely of industrial minerals and mineral products, so that the wider acceptance of cement and concrete technology will have an inevitable and positive impact on the overall consumption of minerals, especially as more and more steel is replaced in buildings.

Although from a mineral perspective this outlook must be very positive, it has been pointed out that the benefits of growth in the industry will largely accrue to the multinational organizations controlling the cement industry in Canada. However, along with the growth of the main industry, it is anticipated that there will be growth in the secondary products industries, particularly in additives and special cement-based products. It is in these areas that a broad suite of industrial minerals might find new applications. Some specific examples in this category include:

- the development and production of a silica-based product as a substitute for silica fume;
- increased utilization of marginal (alkali-reactive) aggregates by virtue of incorporation of supplementary cementing materials, polymer (resin) binders and, possibly, non-Portland cements;
- the production of specialized non-Portland hydraulic cement binders (e.g. magnesia, regulated-set and sulphoaluminate cements) (see Chapter 9);
- the production of mineral-based substitutes for asbestos for use in thin cement panels, boards and other fibre-reinforced products (e.g. mineral and glass fibres, phyllosilicates, vermiculite and perlite, mica and wollastonite);
- the production of low absorptivity lightweight aggregates (possibly clay or shale-based) for low-density ready-mix and precast concrete ;
- high specification and coloured sands for polymer concretes;
- high strength aggregates for high and ultra-high strength (>100 MPa) structural concrete (e.g. traprock, corundum, manufactured, etc.);
- colourful stones for exposed aggregate finishes on panels and flooring;
- thin dimension stone for cladding precast cement and concrete panels (see Chapter 6).

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11. Clay Building Products

- Clay
- Shale
- Kaolin
- (Silica)
- (Wollastonite)
- (Pyrophyllite)
- (Talc)
- (Vermiculite)
- (Nepheline syenite)

Clay, in the form of mud, must be one of the earliest of building materials. Because it will adhere to a variety of surfaces, an early development would have been to bind wood or grass into structures to form walls. Drying blocks of clay in the sun and subsequently firing them into bricks was probably one of the earliest efforts at industrialization of a construction activity, dating to 5000 BC or earlier [1]. Every ancient civilization has left behind a legacy of ceramic and brick materials testifying not only to their utility but also to their durability.

INDUSTRIAL MINERAL CONTRIBUTION

Clay cannot be defined in precise terms. However, for most practical purposes, the description provided by Grimshaw [2], quoting the American Ceramic Society, proves the most useful: "...Clay is a fine-grained rock which, when suitably crushed and pulverized, becomes plastic when wet, leather-hard when dried, and on firing is converted to a permanent rock-like mass."

Clays are found in various forms, ranging from a soft paste (mud), to a soft solid (mudstone), to a laminated rock (shale). Geologically, clays are composed of various minerals of primary and secondary origin, none of which predominates, and all of which are of fine or small grain size. Certain minerals do occur in all clays and have been termed "clay minerals." Of particular importance are the crystalline and amorphous hydrous aluminosilicates of the *kaolin* and *montmorillonite* groups, and minerals related to hydrous mica, termed *illites*.

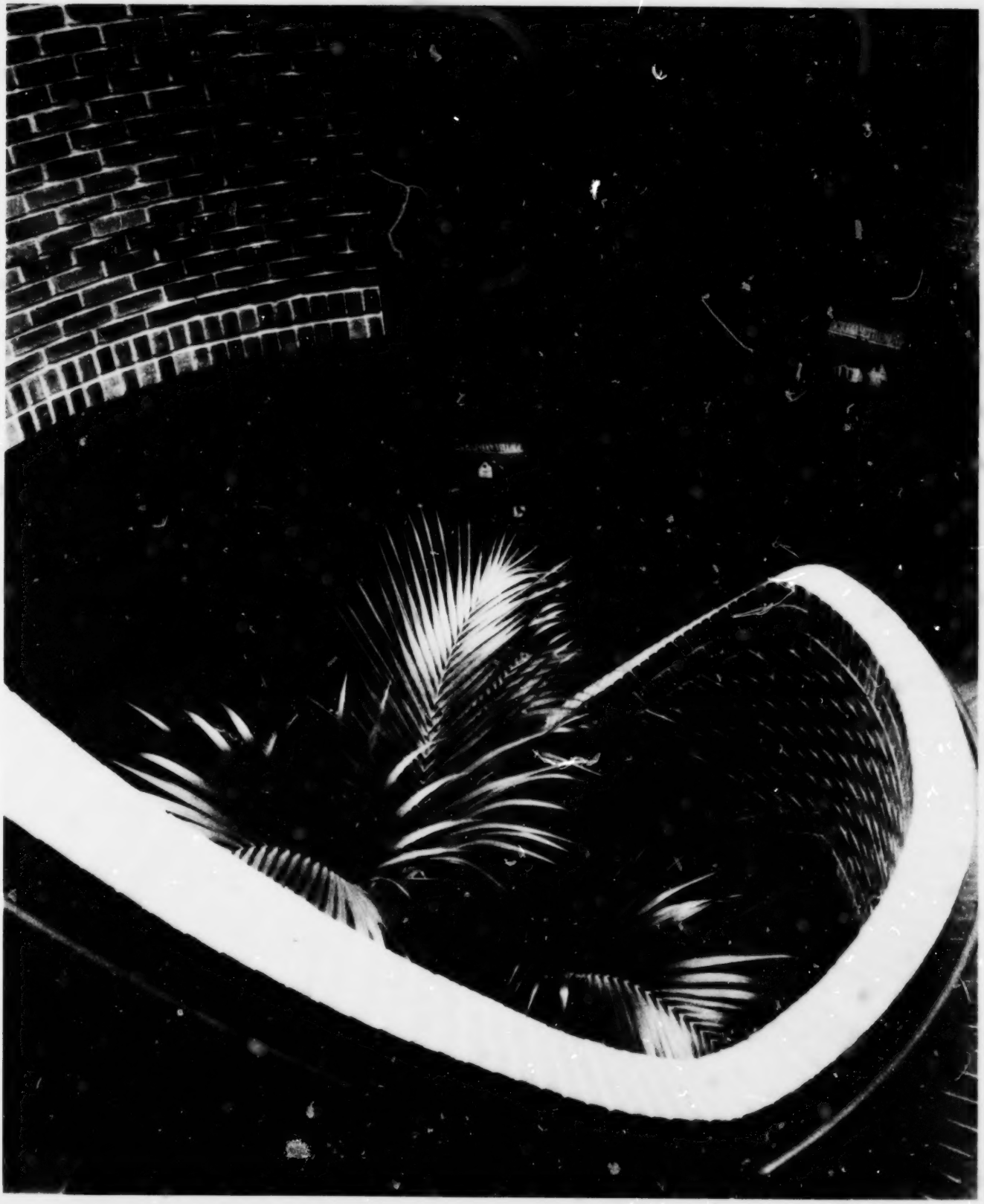
Clays or shales of many compositions can be made plastic with water, moulded into shapes, and fired in kilns to form solid objects for decoration or use. An excellent source of more detailed information on the industrial uses of clays in Ontario, prepared by Guillet and Joyce, was published in 1987 by The Ontario Ministry of Natural Resources [3].

Contemporary building construction employs two groups of products manufactured from clays:

- *Heavy clay products:*
  Bricks, sewer pipe, flue liners, roof tiles, expanded (lightweight) aggregate
- *Fine clay products:*
  Floor and wall tiles, sanitary ware

Mineral wool was also made from clays at one time but is now manufactured in Ontario from industrial waste materials (slag) by processes related to the manufacture of glass products (see Chapter 12).

Since most of the surface clays in Ontario are high in lime and fire to rather soft and porous textures, they are poorly suited as raw materials for fine clay products. The best available raw materials are the Paleozoic shales of the Queenston, Georgian Bay and Arkona formations which are used almost exclusively by the heavy clay products manufacturing industry [3]. Because of the relatively low value of



Architectural use of clay brick. Photo courtesy of Clay Brick Association of Canada.

the products involved, manufacturers of heavy clay products operate production plants adjacent to the shale pits or quarries from which they draw raw material.

Fine clay products require different types of clay, the most commonly used being kaolin. All of the fine clay products manufactured in Ontario are produced from imported kaolins, most of which come from the United States. Imported kaolin is used also as an industrial filler in paper, paint, rubber and plastics (see Chapter 13). The only significant deposits of kaolin clays in Ontario are in the Moose River Basin region of the James Bay watershed. To date, these have not been commercially exploited although their properties have been extensively studied [3].

THE HEAVY CLAY PRODUCTS INDUSTRY IN ONTARIO

The manufacturing of bricks dominates the heavy clay products industry in Ontario. In 1986, after a period of rationalization in the industry, production was distributed between fourteen plants as follows:

Product	No. of plants
Bricks	8
Drainage tiles	3
Other	3

Since the acquisition, in 1985, by Canada Brick of the Domtar operations in Mississauga and Ottawa, the major part of Ontario brick industry has been owned by three companies: Brampton Brick Ltd., Canada Brick Division of Jannock Ltd., and Hamilton Brick Ltd. According to Boucher and Shaw [4], National Sewer Pipe started production of facing brick at its Oakville facility during 1987. With the exception of one plant close to Ottawa, all of the production facilities are located in the Toronto-Hamilton region, where both suitable shales and the principal markets exist. All of these companies own and operate shale quarry facilities adjoining their processing plants, thus being self-sufficient for materials.

In recent years, the Ontario brick producers have been improving their manufacturing facilities, largely to replace obsolete equipment and reduce energy consumption. In 1987, a new brick plant was commissioned by Canada Brick in Burlington; and Brampton Brick has opened a new plant to replace an older facility.

Total shipments of products made by the Ontario industry from domestic clays are given in Table 11-1. The value of these products shipped during the past 20 years (in constant 1971 dollars) is shown in Figure 11-2. The cyclical nature of the industry and the impact of recessionary periods is clearly seen in these data.

Bricks

In 1987, brick sales in Ontario were in excess of 600 million units, representing about 70% of total Canadian sales. To meet this demand, bricks were imported from Quebec, Western Canada and the United States. About 90% of the brick production in Ontario goes to residential construction where both the high rate of construction and the trend towards larger homes in suburban developments have increased consumption over the past few years. The remaining 10% of production is used in architectural, industrial and institutional building, with brick facing being in fashionable demand on a number of public and corporate buildings [5].

Unquestionably, the preferred exterior finish for housing in most of southern Ontario is clay brick. Elsewhere in the province, wood, stone, aluminum and plastic are alternative cladding materials which, for reasons of aesthetics or local availability, may be used in place of bricks. In residential construction the load-bearing function of brick is minimal, its use being largely aesthetic in the form of a veneer surface to cover the frame that supports the house. Exclusion of driven rain, control of air leakage and some insulating value are also benefits gained by use of brick cladding.

With the pattern of use dominated by new housing, the market for bricks is very sensitive to factors affecting housing production. Further, it is sensitive to the demands for luxury housing which favours traditional and natural building materials such as wood, stone, clay brick, floor and roof tiles. Demographic trends (see Chapter 3) point to a gradual reduction in the demand for single-family homes during the period at least to the year 2000. This would project to an increased pressure on the market for clay brick. Conversely, the desire for "lifestyle" buildings, constructed with traditional materials, and the growth of renovation and repair activity (see Chapter 4), suggest that these types of markets may expand.

While the general consumption of clay bricks is currently increasing, there is growth also in the use of alternative masonry materials. Serious competition is being noted from concrete (or "calcite") bricks that are manufactured to duplicate the appearance of clay brick, at a lower price (see Chapter 10). Concrete bricks have been constantly improving in quality and appearance over the last decade. Their durability and range of colours have made it difficult for many home buyers to distinguish them from clay bricks. Concrete bricks are 20–30% less expensive than clay bricks. In 1985, they were selling in the range of $190–220 per thousand, depending on colour and texture, compared with $230 to more than $300 for clay bricks [3]. It has been reported that by 1984 concrete bricks had gained an estimated 25% of the brick masonry market [3]. More recent estimates by the Clay Brick Association of Canada place the market share for concrete brick at about 20% in 1988 [5].

TABLE 11-1 VALUE OF PRODUCTION OF CLAY PRODUCTS IN ONTARIO

Year	Value of Production (000's) Current $	1971 $	1987 $
1967	27,451	31,957	109,420
1968	30,629	34,531	118,236
1969	31,673	34,167	116,988
1970	25,197	26,030	89,127
1971	29,815	29,815	102,088
1972	31,570	30,095	103,046
1973	34,601	30,432	104,199
1974	39,074	30,196	103,391
1975	44,769	30,559	104,634
1976	52,117	32,492	111,252
1977	53,784	31,325	107,255
1978	57,142	31,277	107,091
1979	60,767	30,278	103,671
1980	58,110	26,093	89,344
1981	66,660	27,065	92,669
1982	51,131	18,647	63,849
1983	73,297	25,231	86,393
1984	82,671	27,447	93,980
1985	86,654	27,641	94,642
1986(R)	108,067	32,827	112,400
1987(R)	130,866	38,220	130,866
Total		626,325	2,144,541

Source: ref. [6]

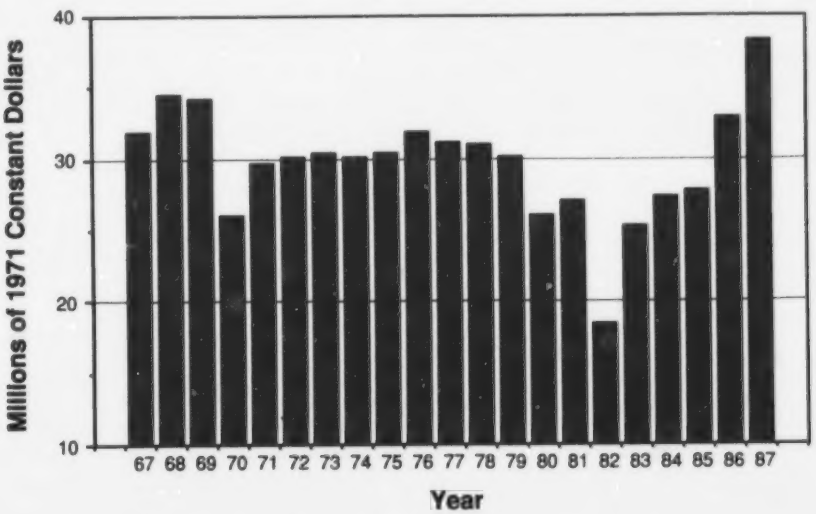


Figure 11-1 Value of production of clay products in Ontario (in 1971 constant $). Source: ref. (6).

Cement-based brick products (precast concrete brick) also appear to be making a considerable impact, both in Europe and in North America, in the masonry pavement marketplace. At one time, flexible pavements for highways were constructed using granite setts (cobblestones) as the wearing surface. As asphalt and concrete materials became available, these were used for road surfaces to give a better riding quality. However, in the early 1970s, the growing congestion of city centres caused planners to realize the need to separate people from vehicles. The solution was to create pedestrian precincts. These areas presented designers with an opportunity to remodel and enhance the built environment and once again to use traditional paving materials that had been abandoned with the advance of automobiles. Some of the most pleasing public spaces in Canadian and European cities have been paved with masonry bricks; however, in many cases, they are made from precast concrete, coloured and textured to appear like clay brick.

In both concrete bricks and concrete pavers, considerable effort is made by the manufacturer to simulate the colour, size and texture of traditional, fired-clay units. This is a manifestation of a factor being observed more generally in building products — substitute materials are being introduced for reasons of cost, durability or convenience in a form that, to the consumer, is not readily distinguishable from the traditional material.

Sewer Pipe

Only one company, Canada Vitrified Products, a subsidiary of National Sewer Pipe Limited, continues to produce clay sewer pipes. In recent years, markets for clay sewer pipes have seen severe competition from concrete pipe in diameters greater than 30 cm and plastic pipe in the smaller diameters. The extent of the impact of competition on the fired clay sewer pipe industry can be seen from the data in Table 11-2, covering the period 1975–1984, a time when large tracts of land were being serviced for construction in areas immediately surrounding the pipe producers.

Large concrete sewer pipes can be made at substantial savings, approaching 50% of the cost of equivalent clay pipes. Concrete pipes have dominated the market in the larger sizes for some years, except in some industrial applications where exposure to corrosive chemicals may require clay pipe.

Plastic pipes cost approximately the same as clay pipes to produce, but the capital investment is much smaller and there are savings in on-site handling and installation costs because of their lighter weight. As a result, plastic pipes are also threatening the market for concrete pipes in the larger sizes.

A similar situation exists for the clay drainage tile that was once used in preparing land for construction. Almost all drainage in new construction is now specified to use plastic (PVC) 6- or 12-inch pipe because of ease of installation. The small quantity of clay drainage tile now made in Ontario is produced for agricultural purposes [3].

Flue Liners

Flue liners for domestic chimneys are made from similar clays and by similar processes to drainage tile at Canada Vitrified Products, St. Thomas plant. While the market seems to be healthy at present, vitrified clay flue liners are facing increasing competition from insulated steel pipe which is more easily installed and less expensive.

TABLE 11-2 CLAY SEWER PIPE PRODUCTION IN ONTARIO

Year	Volume (metres)	Value (dollars)
1975	1,090,818	2,505,256
1976	1,582,621	4,413,478
1977	1,529,652	4,767,616
1978	1,316,285	4,314,289
1979	822,589	3,481,432
1980	407,399	1,777,691
1981*	5,376	23,439
1982	13,247	37,805
1983	64,286	331,071
1984	52,093	399,600

Source: ref. [7]

* National Sewer Pipe's Clarkson plant closed.

Roofing Tile

There is no domestic clay roofing-tile industry in Canada. Successful application of roofing tiles demands a clay body which is durable to freezing and thawing. As with other clays in Canada, Ontario's common surface deposits and the established ceramic shales in the province, do not vitrify to the required density except when over-fired. Investigations of the possibility of manufacturing roofing tiles from Ontario shales have been made in at least three operating plants: Meaford Tile Limited evaluated the Georgian Bay Shale in 1982 with unfavorable results; local clay was used by Hill Tile Limited of Stevenson, Kent County, in a short-lived attempt at commercial production of clay roofing tiles a few years ago; and Dresden Tile Limited also considered clay roofing tile before closing in 1985, but found its fired clay to be too porous [3]. Clay roofing tiles are currently imported from Holland by Great Lakes Brick for sale in southern Ontario.

Even if clay roofing-tile could be made from local materials, the market would be doubtful in the face of potential competition from other products. For example, in the U.K. where clay roofing tiles have an ancient history and are dominant among roofing products on much of the established stock of buildings, 90% of the share of all new roofing materials sold in 1980 went to concrete tiles. Only 5% went to clay products, of which three-quarters was used for re-roofing older homes [3]. Similar concrete roofing products are manufactured in Milton, Ontario by Marley Rooftiles Ltd. (See Chapter 10.)

Expanded (Lightweight) Aggregate

As discussed earlier, low-density aggregates are particularly important as a component of concrete in high-rise office towers and other multi-storey buildings. Whereas the primary purpose of using a lightweight aggregate is to reduce the mass of a concrete structure, some improvement is also attained in thermal and acoustic insulation. In concrete applications, where structural strength is required, lightweight aggregates used are usually made from expanded clay, shale (or slate), blast furnace slag, or fly ash. (See further discussion in Chapters 6 and 10.)

In the present context, the concern is with aggregates made from clays and shales. Some clays will expand on heating to form a cellular bloated pellet or a clinker. Both types of product are suitable for applications in concrete blocks; but for use in poured or pumped lightweight concrete, a sealed aggregate pellet is preferred in which the outer surface has fused during heating.

A number of clays and shales in Ontario are said to show promise for production of expanded aggregate [3]: in particular, the shallow clays of Essex and Kent Counties and the shales of Georgian Bay and the Hamilton Group. The Queenston shale bloats in a narrow temperature range which makes it difficult to use in a rotary kiln but suitable for sinter processing [8].

At the present time, there is no production of lightweight aggregate from clay or shale in Ontario. All the material used in structural concrete comes either from pelletized blast furnace slag or from imported sources. There have been three attempts to establish production in Ontario: the Haydite plant of Domtar Inc. in Mississauaga; the expanded (pelletized) slag production of National Slag Ltd. in Hamilton; and an attempt to produce sintered fly ash at the Ontario Hydro Lakeview power station. Of these, only the National Slag Ltd. operation continues in production.

The Domtar Haydite plant operated in Mississauga from 1928 to 1980, to produce a material with a density of about 650 kg/m^3 from Georgian Bay Shale obtained from an adjoining quarry [9]. The process used four rotary kilns, but by 1980 increasing fuel costs and environmental pressures against dust emissions forced the plant to close. In addition to the closure of the Haydite operation, consumption of lightweight aggregate is reported to have declined in total throughout Canada since 1980 [3]. This has been attributed to a decline in the use of concrete block, a major use for lightweight aggregate, and a failure of the material to maintain a position in the ready-mixed and precast concrete market. (See further discussion in Chapter 10.)

A number of new technical developments have been reported in the production of lightweight aggregates [10-15] that may offer possibilities of reinstituting production from shales in Ontario. In 1983, a Canadian patent [10] was issued to Rohrbach which included means to modify rotary kilns to meet the requirements of modern European production technology based on the so-called Liapore process [16], a successful system used in Germany. Other kiln developments have been made in Britain where shales from coal waste are expanded [11].

If expanded shale is to become a source of lightweight aggregate again in Ontario, it will require consideration not only of technological factors but also of issues such as:

- competition from pelletized slag;
- the establishment of markets in products other than ready-mixed concrete to offset the impact of cyclical construction activity;
- use in products other than concrete block;
- the use of low energy, low pollution methods of manufacturing.

THE FINE CLAY PRODUCTS INDUSTRY IN ONTARIO

As with clay brick, aesthetic and fashion trends have established wall and floor tiles as important features of commercial, institutional and residential construction in Ontario. World production of ceramic floor and wall tiles is in excess of 700 million square meters per year, more than

one-third of which is supplied from Italy. Japan, Brazil and Spain are the other major producers. More than 90% of Canadian consumption is imported [3].

Among the fine clay products group, Ontario has relatively small levels of production of both floor and wall tiles, and sanitary ware, all of which are made from imported clays. In 1987, all production of floor and wall tiles in Ontario was by three companies. Windsor Ceramic Tile Canada Limited, which commenced production in 1985, is the major producer in Canada. The company operates a new, modern and highly automated facility in Windsor, Ontario. Ultimate capacity of the $32-million plant is expected to reach 2.3 million m^2 of tile per year and to employ approximately 175 people year round. In 1985, Great Lakes Ceramics leased the Thunderbrick plant at Rosslyn, 10 km west of Thunder Bay, to produce glazed quarry tile. The tiles are to be made using a stoneware clay from Rockglen in southern Saskatchewan instead of the local clay and shale which did not prove suitable for Thunderbrick in their attempt to make both bricks and split floor tiles. Clifton Ceramic Tile, owned by Pilkington Ceramic Tile, has reopened a plant (with an annual capacity of 400,000 m^2) previously owned by D.A. White & Co. in Kingston, that had closed in 1982 [3].

While it is not strictly a construction material, sanitary ware consumes industrial minerals and is very dependent upon construction activity for its market. There are three manufacturers of sanitary ware in Ontario: American Standard Products Ltd., Toronto; Crane Canada Inc., Trenton; and Waltec Bathware Division of Emco Ltd., Cornwall. Each of these companies produces traditional ware from china and ball clays imported from the southern United States, together with nepheline syenite and silica from local Ontario sources [3].

DEVELOPMENTS IN CLAY BUILDING PRODUCTS

In recent years, most of the efforts of the brick producers to introduce technological innovations have been in the area of production methods, especially with respect to energy use and environmental control. These efforts have resulted in both a rationalization of the industry and the installation of state-of-the-art production capabilities for brick.

In contrast to the developments in brick production technology, the use of brick in construction has changed little over centuries. Individual bricks are still hand-placed in mortar by skilled masons, in much the same way as the earliest days of this craft. That the brick used in Ontario is used largely to meet aesthetic rather than structural needs has made little difference to the mode of its application. Similarly, the placement of paving brick remains largely a labour-intensive, hand operation.

Though currently in a strong position because of the dominance of clay brick as a cladding product in the southern part of the province, the brick industry faces some potential challenges in the future with respect to labour availability and competition from alternative materials.

Labour-intensive processes, such as bricklaying, are one component of the overall low productivity of construction practice. As such, if the construction industry moves to improve productivity in the face of competition, such practices will become increasingly difficult to sustain. Changes away from the use of brick and its current mode of installation may result.

As noted earlier, the average age of bricklayers in Canada is fifty-six and is increasing, and fewer new tradesmen are being trained [17]. A product that depends for its use on a declining craft is in a vulnerable position as other materials that require less skilled labour for the installation become available.

Also, strong cost competition from masonry products made from concrete rather than clay is being felt by the industry. In times of high demand, this may not be seen as too much of a threat, but as demand declines, the less expensive and increasingly improved concrete products may become more attractive to the construction market.

Opportunities to meet these problems exist in the form of proven technology that has been established for some time abroad, although not widely accepted in Canada. Offsetting the disadvantages of high labour intensity that the use of brick or other masonry products involve are two approaches to improving assembly methods — brick-laying aids, and factory pre-assembly.

Bricklaying Aids

Much of the skill in bricklaying resides in handling mortar to obtain a level, clean and aesthetically pleasing appearance in the finished structure. In Italy, a Keybrick™ system has been developed by Morando Impianti to simplify the bricklaying process and reduce labour costs. Construction using the system involves two parts. First, single brick or cavity walls are erected without mortar or cement by placing bricks one on another so that the grooves and plastic pins reference each unit location; at this stage, steel rods may be inserted into the vertical or horizontal channels for reinforcing, as required. Then, when a wall reaches the height of a floor, liquid cement mortar is run into the holes to fill the vertical and horizontal channels and form a "monolithic" structure. Technically, the system has been well received, but in North America it has proven difficult to commercialize for two principal reasons [18]:

- The bricks are of a special non-standard form and thus entire re-tooling of brick making facilities is required for their manufacture. This means that a major capital investment is required before the product can be introduced to the market.

- The abutting surfaces of each of the units require grinding after firing. U.S. codes require bricks to be denser and harder than their Italian equivalents; this results in a more costly grinding stage.

Factory Preassembly

A second alternative to using skilled labour at the site is to bring elements of the construction process into a factory. In factory-based construction, even if skilled labour is required, time is not lost during bad weather, and quality controls are easier to implement. In the case of masonry construction, factory production has centred on panelization. In general, this favours the use of large cast integral units such as plastic, metal or pre-cast concrete panels, rather than small individual items such as bricks. Forming bricks into integrated wall panels is an obvious response to this market. Factory-assembled brickpanels have been available for more than 25 years, though they have had relatively little commercial success. Two general types of panels are available:

- Full brick, factory pre-assembled panels, that comprise units containing as many as 3500 individual full-size bricks bonded by a typical cement-lime mortar [19].
- Thin brick panels that comprise thin slices of clay brick, bonded to a backing material. Two backing systems have been used: a urethane-plywood sandwich and an asphalt-impregnated fibreboard.

Industry representatives have suggested that some of the early commercial difficulties experienced by producers of brick panels resulted from misconceptions about the nature of the market place [19]. It has been suggested [19] that the biggest problem with brick panels 25 years ago was that the producers were attempting to build a few product lines on a day-by-day, year-round basis. In his opinion, the market was not large enough for this approach to be economically competitive. On the other hand, panels are seen as feasible where factors other than cost favour their use — for example, when working where scaffolding cannot be erected, where weather is a factor, or when construction time is limited. Successful panel manufacturers have built and marketed specialty items: for example, C-shapes, corners, and column-to column span beams.

Overall, brick panels cannot be considered as versatile products, suited to all end uses. A full-brick product is likely to be too expensive for use on a subdivision home, whereas, thin-brick panels, may not be suitable for commercial installations. The two types of products are not readily made by the same type of producer. Masonry contractors appear to be more successful with full-brick panels, while independent manufacturers may be more suited to producing thin brick units [20].

Full-brick panels are produced by masons. They are conventional brick masonry in every way, except that they are produced in factories, using a jig and a template to assist alignment. Because the panels are to be building components, tolerances must be more rigid than for site-placed masonry. Some panel systems contain steel reinforcement and are built with lifting inserts and connectors. The manufacturers of these products claimed in 1984 that in this form they can be competitive with panels made from precast concrete [21]. Full-brick panels of this kind were manufactured by Henry J. Knott Inc., of Baltimore, Md. until 1985; however, manufacture was discontinued because of inability to compete with site-placed brick, although technically the product was successful [22].

Similar panels of steel-reinforced, full-size brick are presently manufactured by Vet-O-Vitz Inc. of Brunswick, Ohio. These have found particular application in renovation and repair of various types of buildings including parking garages, deteriorated brick-faced office buildings, and heritage buildings. Other panelized masonry units are produced by the same company with finishes of glazed and ceramic-coated on shale units manufactured by Stark Ceramics Inc. [23].

Thin-brick panels, a typical example of which is the Pan-Brick™ product made by Pem-Brick of Pembroke, Ontario, use sawn slices of clay brick (Fig. 11-2). These are bonded to urethane insulation foam, made rigid by a backing of plywood. In this form the panels combine sheathing and insulation with an exterior brick finish. The insulating value is reported by the manufacturer to be equivalent to an R value of 8.7 that when combined with R12 batt insulation provides a R22.2 exterior wall [24].

Thin brick panels are lightweight (less than 11 lbs/ft^2). This allows installation at minimum labour cost using basic carpentry skills. Though the products are used on new construction, thin-brick panels have been extensively used as part of renovation or retrofit insulation work and to renovate older structures where original brick or block has deteriorated.

Heritage Applications

As was discussed in Chapter 4 of this report, renovation of urban buildings and repair of historic structures is expected by many observers to play an important role in the future of building materials use. The availability of antique and old style bricks for repairing and enlarging early Ontario homes has been recognized as a significant market by Ontario producers. By using batch-style periodic kilns at some of the older brick plants, these producers have been supplying this rather specialized market. In Europe, some manufacturers have gone to the extent of producing hand-made bricks and tiles for this market.

Guillet and Joyce [3] have noted that the "soft-mud" technique of brick making is particularly suited to production of such units. Because of the poor quality of most surface clays in Ontario, this has failed to become a major part of the industry. However, for the small-scale, special-

ized production needed for renovation materials the European mechanical soft mud technology may be an advantage. In principle, the technology uses a modern mechanical approach to an old manufacturing technique; machines are used to throw "soft mud" lumps of clay into sanded wood mould boxes. The moulds are then automatically inverted onto a conveyor and the green bricks are handled by conventional conveying, drying and kiln technology. This technology is ideally suited to small-scale production, since it consists of small modules which can be easily combined to manufacture larger quantities.

Such a system has several advantages:

- a variety of shapes and coloured products can be manufactured, giving high flexibility;
- the system is simple in concept, and easy to operate with minimal maintenance costs;
- the system is suitable for smaller-scale production with highly efficient periodic kilns.

Plants using this technology operate with a minimum of staff, and could be adopted by a Canadian producer to manufacture "antique" soft-mud bricks aimed at the premium end of the market.

Prestressed Units

Brick started as a structural material, but in recent times it has become mainly a facing product in North America. Competition from concrete and steel originally forced brick out of structural applications. Recent developments have renewed interest in the structural capabilities of brick. By reducing the dimensions of masonry construction and the addition of reinforcement and prestressing, the behaviour of brickwork can be radically changed to produce prestressed diaphragm walls competitive with reinforced concrete [25]. Prestressing exploits the compressive strength of brick, which can be increased if necessary by improving existing properties, while eliminating the tensile forces that a masonry structure cannot withstand.

Sewer Pipe

In regard to other clay products, a development in Britain has been reported that has permitted clay sewer pipe to compete with plastic and concrete products. Hepworth Iron Company (Holdings) Ltd., a subsidiary of Hepworth Ceramic Holdings PLC, is the largest producer of vitrified clay pipe in Britain, supplying nearly 90% of the U.K. market. By introducing a new advanced roller kiln, the company has been able to greatly improve fuel efficiency and produce pipes of superior quality. As a consequence, the company has recaptured a threatened market and about 80% of the total sewer pipe in the U.K. is again being supplied by clay-based products [3].

Floor and Wall Tile

Potential opportunities for industrial minerals in the floor and wall tile industry are to provide the necessary kaolin clays, and to provide other minor minerals used in tile production. All of the Ontario plants currently depend on imported raw materials: namely, ball clay from Ohio and

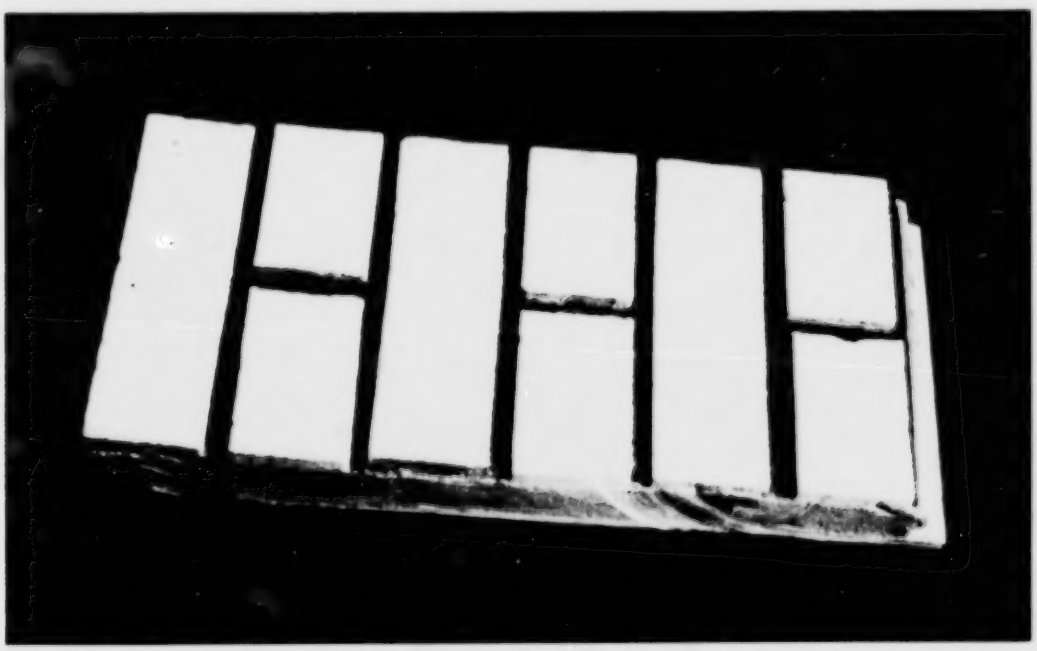


Figure 11-2 Detail of Pan-Brick ™ panel system using sawn slices of clay brick. Photo courtesy of MATEX Consultants Inc.

stoneware clay from Georgia. According to Guillet and Joyce [3], Ontario has the potential to be self-sufficient in kaolin-type clays through undeveloped resources in the Moose River Basin. From a strictly technical point of view, there appears to be an opportunity in Ontario to develop a Northern resource, while at the same time reducing substantial imports of finished floor and wall tiles. It is recommended that this opportunity be given further detailed technical-market consideration.

A spin-off benefit of establishing a tile industry based on local materials might be the consumption of other Ontario-produced mineral additives. For example, North American tile producers use wollastonite, pyrophyllite, talc and nepheline syenite in addition to clay, sand, fluxes and colouring agents, and each of these present a market opportunity to industrial minerals producers.

Fireproofing

An interesting structural fire protection product is now available in Europe. A so-called "Claylath™," consisting of a steel mesh coated with clay and a bonding agent which adheres to the mesh when baked, is attached to partition framework. The lath is then sprayed with a vermiculite-containing coating and the entire system may be covered with wallboard or metal cladding [26]. This system seems to have potential interest for renovation of existing structures where fire protection requires upgrading.

Waterproofing

Clay minerals are well known, both for their ability to absorb and retain large quantities of water, and for their low permeability, once compacted. This characteristic favours their use for lining civil engineering structures used for applications such as water retention in lagoons and leachate control in waste repositories. This same property is exploited in a new waterproof sheeting product from the U.K., termed Volclay Panel™, which is being promoted for the protection of basement walls and other sub-grade structures (Fig. 11-3). The active component of the product is reported to be sodium bentonite clay which is compacted and held between corrugated kraftboard to form a rigid sheet which can be applied to walls [27]. As water infiltrates the sheeting, the bentonite swells to form a gel which is impervious, thereby preventing further flow of water into the structure. Similar products might be produced from Ontario clays.

Geopolymers and Cements

One of the most interesting development prospects for the use of clay minerals is in the area of so-called "geopolymers," a class of materials based on chemically-modified clays. Further discussion of these interesting new materials can be found in Chapter 14. The potential use of clay minerals as supplementary cementing material or as a source of alumina in the production of expansive cements is discussed in Chapter 9.

Figure 11-3 **Installation of bentonite - containing Volclay Panel™ to provide waterproofing for basement wall. Photo courtesy of Volclay Ltd.**

PROSPECTS FOR INDUSTRIAL MINERALS

The use of clay brick dominates both the cladding market in southern Ontario and the heavy clay products industry. It is a mature industry that has recently undergone some rationalization and updated its production facilities. Anticipated declines in the demand for new houses may reduce consumption of brick over the next few years. Prospects for clay building products which may have an impact on the use of industrial minerals include:

- Clay products other than brick have shown a decline in demand as concrete and plastic equivalent materials have displaced sewer and drainage pipes. Clay roofing tiles have not been successfully produced in Ontario, although concrete tiles are manufactured in the province and have established a position in the market.
- Ontario produces no fine clay products from domestic clays, most of which are not suited to the manufacture of tiles or sanitary ware. All production of these products is based on imported clays. Undeveloped kaolin-silica deposits occur in the James Bay area. Some opportunities exist for industrial minerals other than clays to be supplied to the tile industry.
- Using new technology, opportunities exist for a return to the production of expanded shale aggregate in Ontario to meet the requirements for lightweight concrete.
- Opportunities have been identified to reduce the labour-intensity of bricklaying. Systems to aid brick assembly have been available for some time in Europe and the United States, although they have had little success in North America. Panelized preassembled brick has had much more success, with one product type available in the province and others being used in the U.S.
- New product opportunities have also been identified in the area of structural fireproofing and waterproof sheeting using clay.
- A research area, close to commercialization, that could lead to the use of large quantities of clays is developing with geopolymer cements. This area is strongly recommended for further investigation and research. (See Chapter 14.)

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12. Glass Building Products

- Silica
- (Soda ash)
- Limestone
- Dolomite
- (Saltcake)
- (Nepheline syenite)
- Kaolin
- Colemanite
- Fluorspar

Tradition and legend attribute the invention of glass to Phoenician sailors stranded on the shores of Syria. Historically, it is probable that glass was first developed about 4000 B.C. in what is now Syria, where manufacturing glass objects became an art form. The use of glass in architecture is certainly ancient, starting with the use of small lights mounted in lead to form clear windows in houses or stained glass in churches, to contemporary glass curtain wall cladding.

INDUSTRIAL MINERAL CONTRIBUTION

Glass is made entirely from industrial mineral raw materials. Silica (SiO_2) derived from quartzite is the principal constituent (~60%) of all commercial architectural glass products. Several other industrial minerals are used in smaller quantities and in various proportions for different sorts of glass — for example, soda ash (sodium carbonate, Na_2CO_3) to supply Na_2O (~20%); dolomitic and high-calcium limestones to provide MgO and CaO (15-20%); salt cake for SO_3 (~1%); and nepheline syenite (~$\{Na,K\}AlSiO_4$) for alumina (~3%). Small quantities of boron derived from mineral borates are used in the manufacture of glass fibre. Typical batch formulations for flat glass and glass fibre products are given in Tables 12-1 and 12-2.

INDUSTRY BACKGROUND

All glasses are made by forming a melt of the feedstock minerals that is cooled so rapidly that it does not crystallize but remains as a "solidified liquid." The glasses used in architecture or as building components are all transparent to visible light and frequently also to heat. The properties of the glass can be modified by application of coatings to reduce or control both the degree of transparency, and the nature of the radiation transmitted.

Broadly, there are four types of glass building products:

- flat glass — used in windows and curtain walls
- glass blocks — used for windows and decorative purposes
- foamed glass — used for insulation
- glass fibres — used for insulation

A fifth type — glass microspheres, used as fillers for plastics (see Chapter 13) — are not, as yet, widely used in building products. In terms of volume of use, flat glass is by far the most important, being the material from which all of the common window and architectural products are made.

Flat Glass

Historically, there have been three types of flat glass — sheet, plate and float — which are distinguished by their methods of production. Of these, since its introduction by Pilkington Brothers in 1959, the float glass method has become the world's principal production technique and has virtually replaced every other form. In the float glass process, a continuous ribbon of molten glass moves out of the melting furnace along the surface of an enclosed bath of molten tin (Fig. 12-1). The ribbon is held in a chemically controlled atmosphere at a high enough temperature for a period of time sufficient for the surfaces to become flat and parallel. The ribbon is then cooled while still advancing across the molten tin until the surfaces are hard enough for it to be removed from the bath without the rollers marking the bottom surface [3].

After float glass has been made it may be treated to form one of three basic product types which are defined by strength:

- *Annealed glass* — After the glass has been formed it is cooled in a controlled manner (annealing) to prevent stress build-up that could cause breakage.
- *Heat-strengthened glass* — Annealed glass is heat treated to increase strength by a factor of approximately two.
- *Tempered glass* — Annealed glass is heat treated to increase strength four to five times.

Following the processes to strengthen glass, it can be shaped, coated or laminated in numerous ways to form architectural products with a wide variety of forms, colours and radiation transmitting properties.

Glass Blocks

Glass blocks are made by a process that requires pressing molten soda glass into two half-block segments that are then fused together to form a hollow unit. Solid glass blocks, for paving, skylights and panels are also produced. Patterns, colours and reflective finishes can be introduced during pressing, as decoration or to render the blocks semi-transparent.

Foamed Glass

Foamed or cellular glass is a long-established insulation product. It is made from normal soda glass by a melt-foaming technique. The foamed glass fragments are then

TABLE 12-1 TYPICAL BATCH FORMULATION FOR FLAT GLASS

Constituent	Weight (%)	Sources
Silica sand	59	Badgeley Island, Midland, Ont.
High-calcium limestone	5	Beachville, Ont.
Dolomitic limestone	14	Dundas, Ont.
Soda ash	18	Amherstburg, Ont.
Saltcake	1	Saskatchewan
Nepheline syenite	3	Blue Mountain/Nephton, Ont.

Source: ref. [1]

TABLE 12-2 TYPICAL BATCH FORMULATION FOR FIBRE GLASS

Constituent	Weight (%)	Contribution
Silica	28–30	SiO_2
Kaolin	28–28	$Al_2O_3 \cdot SiO_2$
Limestone/dolomite	28–31	$CaO \cdot MgO$
Boric acid	8–11	B_2O_3
Colemanite	11–17	$CaO \cdot B_2O_3$
Fluorspar	1–2	F_2
Soda ash	0–1	Na_2O
Sodium sulphate	0.3–0.8	SO_3

Source: ref. [2]

fused into rigid sheets or blocks that can be used as insulation. The average density of the product is 136 kg/m^3, with a thermal conductivity of 0.04 kcal/m.h.°C. The insulating value is claimed to be equivalent to R-value of 12 for a 4-inch (102 mm) thickness of insulation at 10°C.

Glass Fibres and Mineral Wool

Glass fibres are one of three types of mineral wool products, the others being rock wool and slag wool. All are manufactured in a similar manner, but from different raw materials. Rock wool is produced from a melt containing basalt or diabase, a flux of limestone or dolomite, and a fuel such as coke. Slag wool, as the name implies, is made from blast furnace slag. The fibrous material made from a glass melt, termed glass wool or fibre-glass, is manufactured in three forms: glass wool for use in insulation products, continuous glass filaments and optical fibres.

Two general types of process are used for production of mineral wool for insulation applications [3]. The melt is usually formed in a cupola furnace from which, in one process, it is fed to a multiple disc spinner where fibres are formed by centrifugal action. An alternative method involves passing the melt through slot-type openings in a bushing, and fiberizing the resulting jet with steam.

THE ONTARIO GLASS INDUSTRY

Falconbridge Limited (Indusmin Division) is the major domestic supplier of silica to the container, flat and fibre glass producers in Ontario, with reported capacity of about 500,000 tonnes per year. Quartzite is shipped from Badgeley Island in northern Georgian Bay to Midland for processing [4]. Soda ash is currently supplied by General Chemical of Canada, Amherstburg, which produces about 670,000 tons per year of the material from brine processing operations. Dolomitic and high-calcium limestones are obtained from various sources including Dundas and Beachville, Ontario. A small quantity of salt cake is imported from Saskatchewan for use in flat glass [2]. Nepheline syenite is produced in Ontario at Blue Mountain by Indusmin, the only commercial source in the province [5].

The flat glass industry in North America is dominated by five U.S.-based companies [6]:

- PPG Industries
- Libby-Owens-Ford Co.
- AFG Industries Inc.
- Guardian Industries Corp.
- Ford Motor Company, Glass Division

The Canadian and U.S. industries are completely integrated with two Canadian float glass plants, located in Ontario owned by U.S. producers: PPG Canada Ltd. at Owen Sound, and AFG Glass Inc. with a plant in Scarborough.

Flat glass is used both in construction and in automotive applications. The distribution of flat glass demand in the United States is shown in Table 12-3, from which it is seen that about 60% of the production enters the construction market [6]. Most of the companies in Ontario that are reported in statistical compilations as being in the flat glass industry do not, in fact, produce basic flat glass; rather, they manufacture finished glass components such as window structures for construction and other specialty markets.

Both glass blocks and glass foam are available in Canada, but only from imported sources. Pittsburg Corning Company is the sole North American manufacturer of both products. In addition to the U.S. made product, glass blocks imported from France, Germany and Japan are sold in Ontario.

The North American glass fibre industry is now dominated by Owens-Corning Fiberglas Corp. of Toledo, Ohio, which recently acquired 100% of Fiberglas Canada Inc., the largest Canadian manufacturer of insulation and

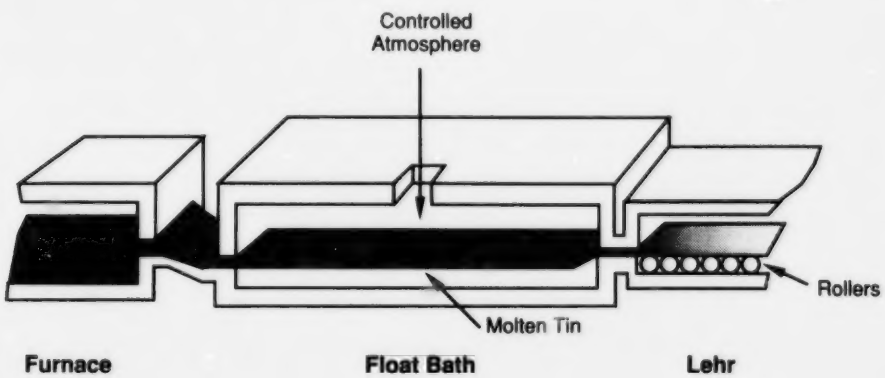

Figure 12-1 Diagram of the float process. Source: ref. (3).

reinforcement fibres with plants in Scarborough and Sarnia, Ontario. Other manufacturers in Ontario are Graham Fiber Glass, Erin, and Ottawa Fibre, Ottawa. Slag wool products are manufactured by the Roxul Company, Milton and Partek Insulations Ltd., Sarnia. Hollow glass (borosilicate) microspheres are "finish-processed" by the 3 M Company in Havelock, Ontario, using raw materials imported from the United States. Other glass microsphere products are imported into Ontario from Quebec, the United States and the U.K.

DEVELOPMENTS IN GLASS BUILDING PRODUCTS

The use of glass in buildings has undergone major growth over the past 10-15 years, with glass curtain wall construction being a major feature of many commercial buildings, and atrium structures being seen in both home and commercial settings.

In some respects, for architectural glass more than for most other building materials, the age of the value-added product has arrived. Basic float glass is a low-cost, bulk product that has changed little in composition or manufacturing technology since it was introduced in 1959. Yet as a building product, in applications and modifications, it is one of the most technically advanced materials used in modern construction. The glass in most buildings, and particularly high-rise office buildings, has become an integral part of the system used to control the indoor environment. In addition to its obvious function of letting natural light enter a building, the modern window structure participates in both energy and acoustic control in the building.

As a consequence of the variety of glass products that have become available through recent technical modifications to basic float glass, the consumer demands a great deal of sophistication from glass products — to the point that the manufacturer must focus on designing glass "systems" where the end product embodies a number of features. Some examples of market segments into which value-added glass products are expanding are given in Table 12-4.

Whether its purpose is to transmit, reflect or absorb light, all architectural glass is designed in one way or another to interact with solar radiation. Solar energy incident on the surface of a window is partly transmitted into the building, partly reflected back to the outside of the building and partly absorbed by the glass, where it dissipates as heat. Usually a glass will affect light in a combination of ways, but one function (reflection or transmission) maypredominate. Solar energy can be considered as composed of three bands of wavelengths in relation to the ways they are sensed by humans:

- *Visible* — the portion of the solar spectrum visible to the human eye, in the range 380–760 Nm.
- *Infrared (IR)* — invisible to the eye, but sensed as heat; this radiation lies in the range 800–2100 Nm.
- *Ultraviolet (UV)* — invisible to the eye, and not sensed by most humans; this radiation is at the low wavelength end of the spectrum (300–390 Nm); excessive exposure to UV can cause skin problems for some people, and it is very damaging to fabrics and finishes in buildings.

The colour of a glass surface on a building will vary with the nature of the glass, the nature of any applied coating and the illumination. It may also appear different when viewed in reflection from transmission, though generally glass is designed so that the light transmitted is similar in colour to natural daylight. The range of appearance available for reflecting glass is illustrated in Table 12-5 for a group of products offered by one Canadian producer.

TABLE 12-3 DISTRIBUTION OF FLAT GLASS DEMAND IN THE U.S. 1984–86 ('M.SQ FT)

Types of User	1984	1985	1986
Construction	2,102	2,233	2,267
Residential	1,503	1,533	1,531
New	719	729	734
Repair/remodelling	784	804	797
Non-residential	599	700	736
New	341	402	423
Repair/remodelling	258	298	313
Speciality*	705	740	707
Automotive	1,055	1,117	1,053
Total	3,862	4,090	4,027

Source: ref. [6]
* includes mirrors, aquarium glass, picture frame glass, vending machine glass and solar panels.

The range of architectural glass products can be divided into four basic types according to the main function required:

- heat-absorbing glass
- ceramic enameled glass
- reflective glass
- laminated glass

Heat-Absorbing Glass

Heat-absorbing glass, also known as tinted glass, was introduced in the 1950s as a means to reduce the solar heat gain through windows. These are transparent glasses, coloured through the entire thickness. The original products were green; other colours have since been added. The green-tinted product remains the most efficient in terms of combining light transmission with heat absorption [8].

Enameled Glass

Ceramic enameled glass is a non-transparent decorative product made for cladding surfaces. The original products were popular many years ago and have now been replaced by ceramic tiles. However, new products that combine the enameling process with the heat treatment of the glass are more durable and are again finding applications in non-vision areas of buildings, typically on spandrel panels. New products of this type that have recently been developed can simulate the appearance of polished granite or marble.

TABLE 12-4 EXPANDING MARKETS FOR VALUE-ADDED PRODUCTS

Residential:
Insulated glass — penetration moving from 68% in 1982 to 77% in 1988
Low-E — penetration moving from 0 to 25–30% by 1990
Skylights — increasing from 600,000 units in 1982 to over 1,550,000 in 1988 (tempered and laminated glass)
Sunrooms/solariums — market continues to grow (tempered and laminated glass)
Non-Residential:
Reflective glass
—high performance (sputtered, off-line)
—medium performance (pyrolytic, on-line)
Skylights (tempered and laminated) — increasing use
Sloped glazing (tempered and laminated) — increasing use
Insulated glass — increasing use, penetration from 51% in 1982 to 76% in 1988
Low-E glass for commercial use — increasing use
Bent glass — increasing use
Tempered glass — increasing use
Laminated glass— increasing use
Acoustical glass — increasing use
Source: ref. [6]

TABLE 12-5 REFLECTIVE INSULATING GLASSES

Designation	Coating Colour by Reflection	Colour by Transmission
Solarban 470	dark blue	neutral
Solarban 550	neutral silver	neutral
Solarban 560	bright silver	neutral
Solarban 565	medium bronze	neutral
Solarban 570	light to medium blue	neutral
Solarban 575	copper/topaz	neutral

Source: Manufacturer's data given in ref. [7]

Reflective Glass

By the 1960s, commercial buildings were using glass in curtain walls. In order to reduce the cooling load imposed on the air-conditioning systems, it was necessary to provide shading over and above that of heat-absorbing glass. It was found that by applying a thin layer of some metals or metal oxides on glass a semi-transparent, reflective surface could be formed. In addition, a totally new aesthetic quality was possible. Since their inception, many new processes have become available to manufacture durable coatings on glass, and a wide range of products is offered. One of the more recent developments has been the creation of thin films with high visible light transmission combined with low emissivity. Low emissivity coatings (low-E glass) can increase the insulating value of glass by 50%.

Laminated Glass

Contemporary architectural designs frequently use glass in sloped or other overhead installations. In these cases the designer is presented with problems of owner liability in case of breakage, property security, weather protection and support of snow loads. Laminated glass is frequently being specified to meet these needs, and consists of two or more lights of flat glass, with a tough, transparent layer of vinyl plastic sandwiched between them. The lamination is conducted under heat and pressure to form a single unit that is both transparent and tough. Tinted and heat-reflective glasses can be used to form the laminate, to incorporate aesthetic and functional properties.

Insulating Glass

Attaining insulation value through the use of glass, or more accurately, reducing the heat loss from buildings that occurs through glass surfaces, has lead to the development of the Insulating Glass (IG) unit. A typical IG unit (Fig. 12-2) comprises two or more lights of float glass separated by a spacer sealed in a frame (usually aluminum or wood). The space between the glass lights provides a layer of static air through which heat loss by conduction or convection is reduced. Other heat control functions, reducing heat input or loss, are introduced through the use of coatings or laminates, an example being the use of low-E or multi-function coatings in an IG unit.

The availability of IG units with a seal life of over 30 years has permitted the development of more complex functions. For example, acoustic attenuation (noise reduction) can be greatly increased by filling the space between lights with argon gas and using mismatched thicknesses of laminated glass.

Recent developments in IG units allow for an element of "smart control" in radiation transmission through windows. Boy and Meinhardt [9] report the development of a temperature-dependent light transmission polymeric gel (TALD) that can be placed in the space between lights in an IG unit. Placed in layers ~0.3 mm thick between transparent elements (lights), it works through a clouding mechanism, as a self-regulating temperature dependent screen. The clouding mechanism can be achieved in two ways. The first mechanism is temperature-dependent control of water-soluble, filamentary macromolecules. In the transparent state, the polymer macromolecules are completely dissolved in water. In this state, the molecular diameter is smaller than the wavelength of visible light, and the solution is transparent. As the temperature increases, and consequently as heat entering the building increases, macromolecular chains begin to form to dimensions greater than the wavelength of visible light, and clouding of the solution results. The temperature at which clouding occurs can be regulated to within ±1.5°C in the range of 9–90°C. In the second mechanism, wetting agents in the gel bind water due to polar interactions. At low temperatures this binding is stable and the gel is transparent. As the temperature rises the bound water is released as small water droplets in the plastic gel, forming a fog-like clouding. The process is reversible and can be adjusted to a precise temperature by the addition of chemical agents to the gel.

Fire Protective Glass

An interesting variation of a low heat transmission glass unit is available from the Saint-Gobain group of companies in Belgium. Termed Contraflam™, and produced by Vereingte Glaswerke GmbH, the product is offered as a "fire protective glass" that can be used where previously wired or block glass would have been required. It is claimed that the product acts as a radiation shield to prevent the passage of heat radiation during a fire. Heat radiation is one mode of fire spread in a building where carpets and furniture can be ignited even when direct flame spread is not possible. The company literature describes the product as a system comprising two tempered safety-glass sheets separated by a metal spacer and sealed by a two-barrier system. The cavity between the two sheets of glass is filled with a clear and fully transparent gel capable of absorbing heat radiation. The gel is a polymer containing a high degree of water and inorganic salts.

Electrochromic Glass

Still at the research stage are glass coatings that can be darkened or change colour in response to an external electric current — so called "electrochromic coatings." The electrochromic effect can be obtained by building up on a glass surface a series of thin films of semiconducting metallic oxides (such as tungsten oxide), or complex organic molecules [10].

Glass Blocks

Glass blocks were invented in Europe in the early 1900s. Once regarded as an "architectural" product, they appear to be regaining favour both for home and commercial construction. They are largely a decorative product and cannot be used for structural purposes. A wide variety of colours and thermally-bonded solar reflective finishes are available. Commercial products are produced in nominal 6 x 6 inch and 12 x 12 inch (and metric equivalent) sizes. The blocks are installed by masonry techniques using a mortar based on Portland cement and lime, incorporating a water-proofing additive for exposed applications. The development of simplified methods of installation, based on spacers and channels, has brought glass blocks into the "do-it-yourself" market. It is reported that in Europe as much as 40% of glass block is sold for use directly by homeowners [11]. This would suggest potential interest in these products to the renovation market.

Foam Glass

Various methods are described in the patent literature for manufacturing cellular foams from a range of precursor alumino-borosilicate and soda-lime silicate glasses [12]. The high manufacturing costs associated with these high quality starting materials are considered by Hojaji [13] to be a significant factor restricting the more widespread use of structural foam glass products in building. In a recent study, the same author reported the development of foaming processes using a range of lower cost raw materials including siliceous minerals such as silica sand, diatomaceous earth, bentonite, feldspar and apatites, and industrial wastes, such as fly ash, bottom ash and kiln dust.

Glass Fibre and Mineral Wool

Glass and mineral wool insulation are mature products which are facing increasing competition from polymer-based foam plastics such as polystyrene (see Chapter 13). This trend is expected to continue unless, as noted earlier in Chapter 4, building codes are extended to reduce sources of smoke and fume hazards in construction products. In this event, the mineral-based insulation products will continue to offer significant advantages over polymer products in terms of lower release of smoke and toxic fumes in the event of fire, a situation which will appeal to the consumer.

Further demand for glass fibres will accompany the development of the new materials and technologies, described elsewhere in this report, particularly in applications where reinforcement is required: for example, as an alternative to steel, polypropylene and other fibres in cement and concrete products (Chapter 10); use in plastics and other polymer-based products (Chapter 13); and as an asbestos replacement in spray-applied fireproofing and cement boards (Chapter 14).

Glass Microspheres

Both solid and hollow glass microspheres are finding increasing uses as fillers, particularly for engineering plastic composite applications. Penetration of engineering plastics into the building products market could provide a major growth opportunity for these high value-added products.

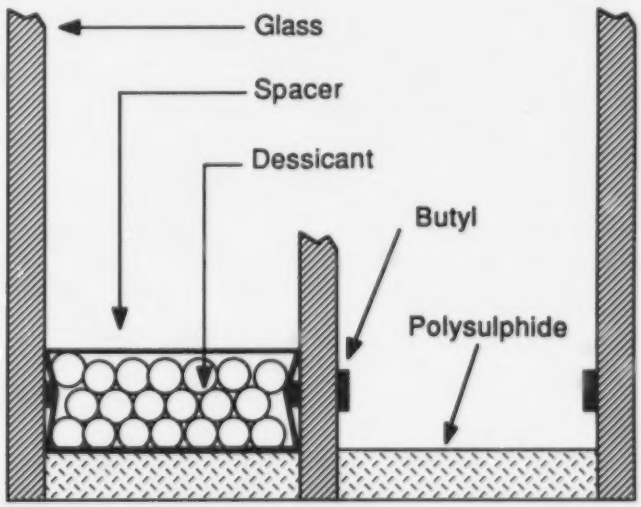

Figure 12-2 Structure of a typical insulating glass window unit.

PROSPECTS FOR INDUSTRIAL MINERALS

Although the use of glass in construction is clearly a strongly growing area, the capital-intensive techniques for manufacturing flat glass, and the dominance of a few, multinational companies in this industry, suggest that the opportunities for industrial minerals will lie largely in increased supply of existing industrial minerals (most notably silica) by current producers. The increased demand for glass building products may present an opportunity for increased consumption of provincial sources of silica.

The foamed glass and glass block product areas would also appear to offer more opportunities for import substitution by local producers, using Ontario minerals. It is recommended that the technology and market viability of these areas be investigated further to establish the potential for development of Ontario-based industries.

A number of plastics made from acrylic or polycarbonate materials are now offering competition to glass. These materials are marketed on the basis of high impact resistance in comparison to glass; however, they have inherent disadvantages in that they are combustible and subject to scratching by abrasion. Their use has been growing for overhead glazing, decorative skylights and "porthole" windows in institutional structures and for ballistics protection glazing. Imitation stained glass decorative windows have been made from both plastic types. Neither product contains any industrial mineral component. (See further discussion of polymer-based glass replacement materials in Chapter 13.)

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13. Polymer-Based Building Products and Filler Minerals

- Calcium carbonate
- Kaolin, attapulgite
- Talc, pyrophyllite
- Silica
- Wollastonite
- Mica
- Diatomite
- Perlite
- Vermiculite
- Nepheline syenite
- Calcium sulphate
- Barite

Naturally occurring polymers have always been part of building construction; applications range from the reinforcement provided by natural fibres to the use of resins as adhesives. Modern construction practice, however, has seen a major increase in the use of synthetic polymers, sometimes taking the form of products manufactured traditionally from industrial minerals. The principal areas of polymer use are in paints, adhesives, sealants, and insulation, and as plastic components serving a wide range of functions (Fig. 13-1). Potential applications for polymers in construction are summarized in Table 13-1.

The processing of plastics is the fastest growing industry in Canada, with a growth rate averaging more than 2.2 times real GDP for the past 20 years [1]. In 1986, the Society of the Plastics Industry of Canada reported that ~26% of the output of the plastics industry went into construction, with further increases to ~29% expected by 1996; and that building construction is second to packaging in consumption of plastics in Canada [2]. In terms of domestic consumption of plastic resins, pipe and associated fittings are dominant among construction products (Table 13-2). Industry experts in the United States anticipate that construction will be the fastest growing market for plastics, with predictions for the next decade that major advances will be made in structural, decorative, glazing and insulating applications [3].

Polymers are a product of the petrochemical industry. With the exception of polysiloxanes (silicones) and the use of some mineral-based processing aids, industrial minerals play only a small part in this industry. Thus, when polymer products replace traditional building materials, they present a *competitive* threat to the current status of some industrial minerals. The competition from plastics arises from certain advantages they have over mineral-based products — for example, their light weight, the relatively low energy required for processing, their resistance to aggressive environments, and their ready compatibility with industrialized fabrication methods. The low weight and ease of processing, in particular, are a significant advantage to plastics in industrialized fabrication: they can be formed, welded, cut and glued in rapid, automated processes, and unlike cement-based materials, forming and curing cycles require little time, meaning that productivity can be high.

However, plastics and other polymer-based materials do have certain disadvantages as building materials, largely as a result of their low melting point and consequent limited thermal stability. First, some polymers may contain or emit small quantities of volatile constituents during normal service, or as a result of degradation; these may cause odours and poor indoor air quality which, in poorly ventilated buildings, may induce symptoms such as nausea and headaches. Second, and of much greater concern, is the potentially lethal release of hazardous fumes by some plastics in a fire in buildings. [3,4].

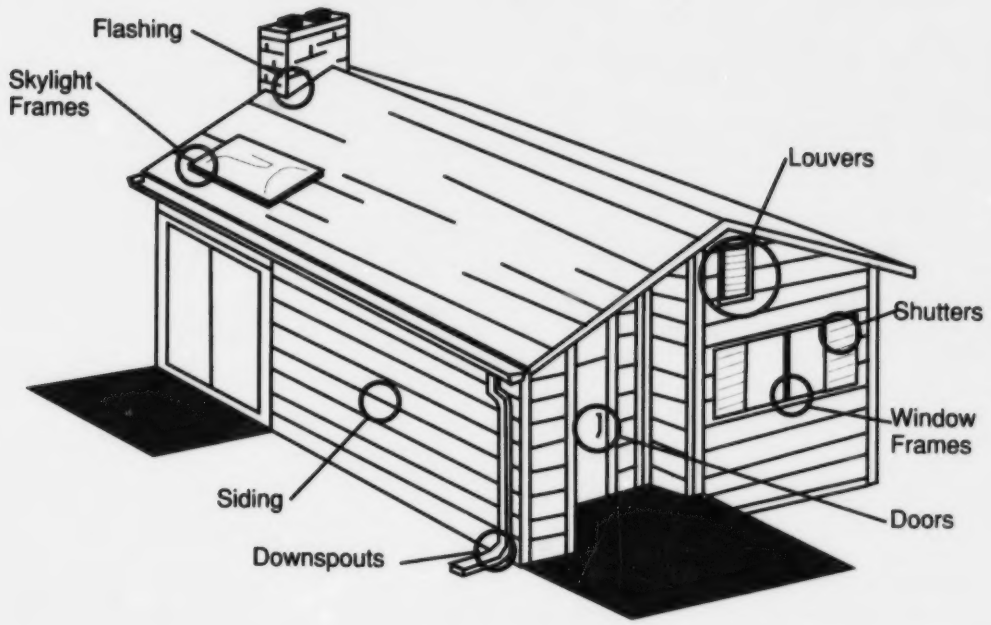

Figure 13-1 **Potential uses for plastics in common building products. Source: MATEX Consultants Inc.**

TABLE 13-1 TYPES OF POLYMER-BASED BUILDING PRODUCTS

Function	Product Types	Function	Product Types
Adhesives	Glues and resins	Coatings	Paints and varnishes
Flexible sealants	Putty, caulking, and weather stripping	Drainage	Sewer and wastewater pipes, rainwater control
Cladding	Shingles, roofing membranes, siding, vapour barriers, ceiling tiles	Trim and fixtures	Door and window frames, baseboards, lighting fixtures
Flooring and paving	Tiles, linoleum, asphaltic and polymer concretes, carpeting	Conduit	Electrical conduit and drinking water pipes
Thermal insulation	Foams, beads, sheeting	Miscellaneous	Composite materials used as grouts, glazing, manufactured stone, sanitary ware, etc.
Electrical insulation	Conduit, tape		

At the outset, it should be noted that only a small percentage of the structural materials used presently in contemporary buildings is polymer-based. The overwhelming proportion of polymeric materials is added to a building after construction is complete — for example, in paint, floor coverings, furniture, fixtures, and office or domestic equipment and appliances.

Perhaps the best documented, and certainly the most studied problem relating to plastic materials in Canadian housing structures, has been the issue of urea formaldehyde foam insulation (UFFI), a foamed-in-place material that was used for retrofitting residential buildings during the late 1970s. In some, but not all, homes with UFFI, there is evidence of formaldehyde gas emissions from the insulation, and of fungal growth in the insulated cavities. In some of these homes, one or more household members have experienced adverse health effects believed to be related to the presence of the UFFI. The odour of formaldehyde gas is one of a number of odours which may be emitted from a cavity containing UFFI. Other odours can be related to moisture. Fungal growth often produces a musty odour [5,6].

The health problems potentially caused by exposure to formaldehyde gas in air include eye, nose and throat irritation, coughing, headaches, dizziness, and, in very high concentrations, bronchopneumonia and pulmonary oedema [5,6]. In addition to problems caused by the formaldehyde gas, some of the fungi that may form in UFFI-filled cavities may induce respiratory problems in humans.

It should be pointed out that UFFI insulation in building cavities is not the only potential source of formaldehyde in buildings. Furniture, upholstery, carpet backing and other fixtures and fittings are made from UFFI foams and other formaldehyde-containing resins.

However, the reaction of the public, and the subsequent discontinuation of use of this otherwise effective insulation product, testify to the growing strength of the consumer's role in selecting building materials.

While primarily representing competition, at the same time, some polymer-based products offer *opportunities* for the use of industrial minerals as fillers, extenders and reinforcing agents. Many manufactured materials contain fine particles or fibres that are incorporated to reduce their cost, influence their properties, or modify their performance. Particles used in this way are generally termed "fillers" or "extenders," while fibres are commonly used as reinforcing agents [7].

The finished product in which a filler or reinforcer has been included is frequently termed a "composite" material. The simplest composites comprise a binder, such as cement or a plastic resin, and a single type of filler or fibre; more complex examples involve the use of a number of particulate types. While the use of polymers is increasing, and a growing number of materials employing fillers and reinforcing agents are being used in buildings, the majority of filler materials are used in other types of manufactured products as components in consumer goods, cars, aircraft, boats and high-technology equipment, etc.

There is some confusion over the term "extender," which is often used synonymously with "filler." More correctly, "extender" refers to a finely-ground mineral that is used as a carrier for a more expensive material (e.g. a pigment), as a means to increase the bulk of an expensive powder, or to displace an expensive resin in a polymer or liquid-based system (e.g. in paint). In contrast, besides filling space, a "filler" may have several roles in a composite — for example, the provision of increased thermal stability or increased stiffness, without deleteriously affecting other components in a system. In general, a "filler" is used to impart some desirable function to the product in which it is included.

Platy materials such as talc and mica are used to provide some degree of reinforcement in composites, usually manifested by an increase in stiffness in the product with a minimal loss of tensile strength. However, by far the best reinforcing agents are materials in a fibrous form. There

TABLE 13-2 ESTIMATE OF RESIN CONSUMPTION IN BUILDING PRODUCTS BY CANADIAN PLASTICS MANUFACTURERS

Product type	Total (000 t)	Expected Growth (%/yr) (1986/91)	(1991/96)	Estimated Market (000 t) (1991)	(1996)
Pipe and fittings	145	7	5	203	260
Flooring	16	4	3	19	23
Siding	46	13	11	85	143
Cladding	13	5	4	17	20
Window frames, etc.	25	11	14	42	81
Mouldings, etc.	6	4	3	7	8
Bathroom fixtures	7	6	5	9	12

Source: adapted from data in ref. [2]

have been many attempts to define a fibre; most agree that the principal property is a high ratio of length to cross-sectional area or width (aspect ratio), of the order of 10:1 or 100:1. Fibres of most materials have a higher tensile strength than the bulk material from which they are made; thus, when high strength fibres are used in a composite, strengths greater than the bulk matrix material (e.g. cement or plastic) can be attained. In addition to strength, modulus (or stiffness) and toughness are important in some materials — when a fibre of high modulus is added to a matrix of low modulus, stiffness and strength are imparted; and when a fibre of low modulus, such as a polymer, is added to a brittle matrix (such as cement), toughness is induced. Composites can, therefore, be designed by careful selection of components to meet a number of demands in service.

The use of fillers and reinforcers in polymer-based building products is only a part of their general application in manufactured goods. Without regard to the end applications, certain general features are relevant to the current widespread use of fillers throughout industry. Overall, they bring two important advantages to the production, economics and performance of materials:

- In product formulations, fillers or extenders reduce the requirement for expensive matrix components such as resins in plastics, solvents and extender pigments in coatings, elastomers in rubbers, and bitumen in asphalts.
- By careful selection of the appropriate filler(s), the engineering properties of a polymeric matrix may be modified; for example, by increasing stiffness, strength or impact resistance, improving casting or moulding characteristics, reducing thermal expansion, or controlling density or thermal conductivity.

A more detailed discussion of the relationships between mineral types, filler uses and the current status of the Ontario fillers industry is presented later in this chapter. Prior to discussing these issues, it is necessary to give some consideration to the nature of the polymer-based building products that use fillers, and their relationship to the use of industrial minerals.

POLYMER-BASED PRODUCTS AND THE ROLE OF FILLERS

Two groups of polymer-based building materials may be considered in relation to industrial minerals use, on the basis of the extent to which they compete with mineral-based products (Table 13-3). The first group comprises products which are largely related to coating, sealing and waterproofing functions in buildings: for example, membrane materials, adhesives, paints and sealants that cover, coat or fill the surfaces and spaces between other materials such as glass, metal, wood, stone or wallboard. Historically, this group of materials has been made from polymeric components, frequently blended with finely ground mineral fillers — a typical example is the traditional glazing putty compounded from linseed oil and calcium carbonate. As new types of materials have been developed to meet these functions, they have generally continued to require the use of mineral fillers and they have presented opportunities rather than threats to the status of industrial minerals.

The second group of polymer-based products comprises plastics such as PVC, polystyrene, and polypropylene. These threaten more directly the market position of traditional building materials such as wood, metal and industrial mineral-based products (Table 13-4). In functions such as cladding, flooring, trim, window frames, water and waste piping, and decorative tiles, plastic products represent competition for gypsum-, clay- and cement-based materials. The extensive use of foamed polystyrene as insulation is also in direct competition with glass or mineral wool and loose insulation products such as vermiculite.

TABLE 13-3 POTENTIAL APPLICATIONS FOR VARIOUS POLYMERS IN CONSTRUCTION

Type of Polymer	Typical Construction Application
Acrylonitrile-butadiene-styrene (ABS)	Drain waste and vent pipes, plumbing fittings
Acrylic	Signs, skylights, safety glazing
Epoxy	Coatings for metal panels, flooring, polymer concrete, wall panels
Polycarbonate	Vandal-resistant glazing
Polyester	Artificial stone, polymer concrete, sanitary ware, floors, tanks
Polyethylene (PE)	Vapour barrier, piping, cable insulation
Polystyrene	Construction panels (rigid type) Thermal insulation (foam type)
Polyvinyl chloride (PVC)	Siding; electrical conduit; cable insulation; drain, waste, and vent pipes; wall and floor coverings; water pipes; window frames
Styrene-acrylonitrile	Safety glazing

Source: adapted from ref. [8]

TABLE 13-4 PRODUCTS IN WHICH COMPETITION IS LIKELY BETWEEN PLASTICS AND INDUSTRIAL MINERALS

Product Types	Industrial Mineral Products Affected
Pipe and fittings	Clay, cement, aggregate
Insulation	Glass, mineral fibres and vermiculite
Flooring	Clay tiles
Cladding	Clay and concrete masonry, stucco
Bathroom fixtures	Clay products
Glazing	Glass
Partitions and decorative laminates	Wallboard
Polymer concrete	Cement

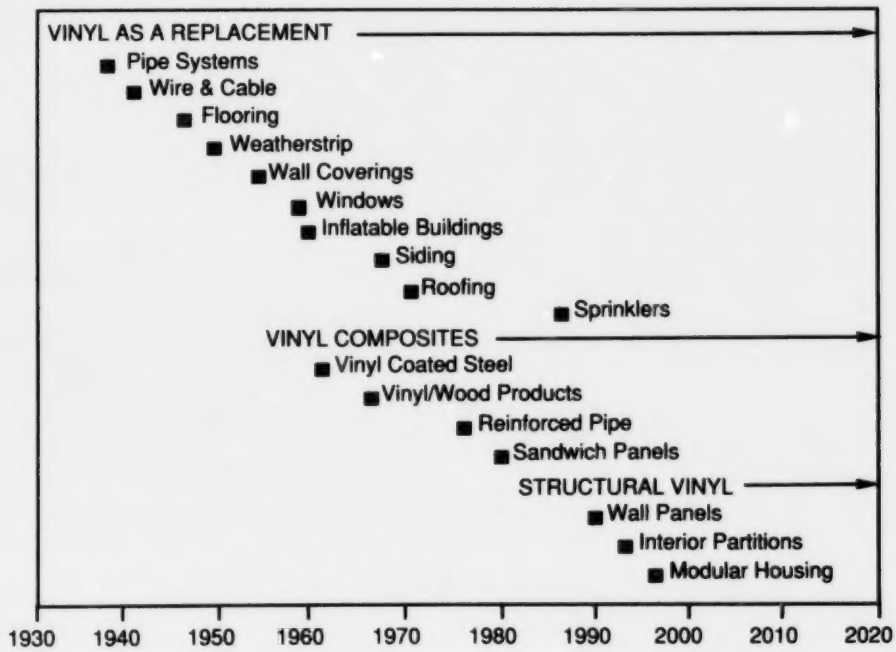

Figure 13-2 Vinyl application trends in construction. Source: ref. (9).

By far the most important and versatile plastic used in construction is polyvinyl chloride (PVC). It may be used in most parts of the skin and in many fittings in buildings. As early as 1930, "vinyl" was used in pipes and wiring insulation. Vinyl flooring was introduced in the 1950s. By the 1960s, it had become a major contender in exterior cladding, and now is used widely in roofing. A major example of its use as a roofing membrane material is in the Toronto Skydome. The retractable roof of this building covers eight acres and some 70,000 seats. It is constructed of a deck supported by a steel frame, the outer surface being covered with reinforced PVC.

Markets for vinyl in construction, presented in terms of historical and projected trends, are given in Figure 13-2, after Yeshin [9]. He considers that the key to future growth will be as a replacement for other materials, particularly in the structural area. Vinyl construction applications can be categorized into three subsegments [9]:

- *Construction systems:* pipes and fittings, electrical supplies, air barriers
- *Exterior products:* windows, doors, sidings, exterior finish, fencing and landscaping, siding, signs and awnings, roofing
- *Interior products:* flooring, wall coverings, window treatments, modular wall systems, furniture, ceilings, trim applications, store interiors

Windows probably represent one of the fastest growing markets for vinyl polymers in construction. Industry predictions call for vinyl to penetrate up to 20% of the window market by 1990 [9]. Up to 45% of windows in new construction in West Germany are made from vinyl plastics. The popularity of vinyl frames for windows results from their durability, low maintenance requirement, corrosion resistance and ease of installation. Vinyl siding is the most frequently specified material for residential renovation [9] and continues to make inroads in the commercial market. Vinyl fencing and landscaping are also becoming popular in residential construction. Rigid PVC pipe has been used since the 1930s and is now a major application for the polymer. From the perspective of the industrial minerals industry, PVC presents the most serious potential competition among plastic construction products.

Though the principal impact of plastics in building products is as competition to industrial minerals, there are some opportunities available for certain mineral products to find new markets as a consequence of the growth in the use of plastics. Over the past 10 years, almost half of the growth in mineral consumption in plastics has resulted from composites replacing traditional materials. The automotive, aerospace and appliance industries have led in these developments [10], but there can be no doubt that such materials as PVC pipe and siding have contributed to this trend. The plastics industry is strongly based in materials research; its products are designed to be applied in all types of situations, some requiring exceptionally high performance standards. Generally, it is an industry ready to compete from a position of considerable technological strength. It is, therefore, important for the industrial minerals industry to understand the potential advantages and disadvantages of plastics in construction materials if it is to meet this competition successfully.

To a large extent, mineral-based products will have to compete directly through development of advantages in cost, convenience and performance. The new industrial mineral products discussed in other chapters of this report will go some way to strengthen the competitive position of industrial minerals. To a lesser degree, the opportunities for minerals in plastic products may offset some of the impact resulting from markets that will inevitably be lost to the plastics industry. We now examine some established applications and developments for industrial minerals as they are in commonly employed in polymer-based building products.

Asphalt Products

Raw asphalt is a complex mixture of bitumens and other low-volatility organic chemicals which are recovered from petroleum refinery residues or natural deposits. The brown-black solid or semi-solid material has thermoplastic properties and has found use, traditionally, as a low-cost cementing agent, particularly in asphaltic concrete for road paving, and in a range of other construction-related applications:

- Asphaltic concrete
- Bituminous grouts and mastics
- Specialty paints
- Roofing shingles
- Sealing and jointing compounds
- Pipeline and underground cable coatings
- Roofing membranes, rubberized asphalt
  asphalt cutbacks
- Roof resaturants
- Rust-preventative coatings
- Base for synthetic turf
- Floor tiles

Asphaltic concretes are widely used for paving roads and parking structures, and are major consumers of mineral aggregates in the province (see Chapter 6). Mineral fillers used in asphaltic concrete (most commonly low cost limestone, dolostone or silica rock dusts) are used to improve the engineering properties and to conserve bitumen. Filler levels for asphaltic concretes are in the range 5–6%. The asphalt coating on shingles, the most widely used residential roofing surface material in the Ontario, is commonly filled with 50–60% of low-cost, coarse grades of calcium carbonate filler, to increase the viscosity of the molten asphalt and to add weight. Coarse calcium carbon-

ate, or other mineral granules, is also used on the outer surface of the shingle to protect the asphalt from the effects of prolonged exposure to sunlight. Filler levels for rubberized asphalt and floor tiles are in the range 35–50%. While asphalt products represent a mature market, developments continue in many areas, usually with emphasis on improving durability.

Putty, Caulking, Sealants, and Drywall Jointing Compounds

Putty, caulking, and sealants are a group of related products, linked to the plastic and rubber industries. They are used to seal joints and seams, or to fill cracks. Calcium carbonate fillers are extensively used in all of these products as low cost extenders to the resins. Though high brightness is required for most products, off-white fillers are used in some applications. Typical filler loadings are 40–50% and may go as high as 90%. The actual loading is determined, in part by material costs, and also by the filler properties. For sealants, it is important that the flow properties and extensibilty of the finished product are controlled. Other types of fillers used include barite, kaolin, silica and talc.

The joints between adjacent sections of wallboard are closed by a thin tape or strip which is then overlayed with drywall jointing compound to provide a smooth, uniform surface. Joint compounds are typically composed of over 90% by weight of ground calcium carbonate and other mineral fillers such as mica, kaolin, gypsum, and talc dispersed in a polymeric binding medium (usually PVA). Asbestos was at one time a major constituent of drywall jointing compounds, and substantial product investigation has been conducted by manufacturers to find substitute materials and formulations to permit its withdrawal from this application. Wollastonite appears to be developing as a major fibre component in some joint compounds. The joint compound industry is concentrated, with the major wallboard manufacturing companies (see Chapter 8) accounting for roughly 70% of production. Substantial growth in the use of wallboard has been responsible for high demand for jointing compounds over the past few years [11], and development of new products continues in this area.

Adhesives

Many materials, some of which contain fillers and extenders, are used as adhesives in construction. Typical filler content is in the range 10–30%, but may be as high as 80% of the weight of the adhesive. Kaolins are the principal filler in adhesives, with calcium carbonate next in total tonnage, accounting for over 68% and 24%, respectively, of the volume used. However, from the perspective of this report, it must be noted that most adhesives are formulated for use in manufacturing products not associated with construction: for example, in the United States, it has been estimated that construction applications account for ~24% of adhesives consumption (Table 13-5), with the corresponding consumption of fillers totalling ~25,000 tonnes/year [12]. An annual growth rate of ~7.0% (over the period 1986–1991) has been estimated for specialty adhesives used in construction, in comparison with ~5.3% for all applications [13].

Construction adhesives are employed for structural assembly of panels, gypsum board, and concrete, and for bonding tiles and laminates. Environmental regulations are tending to favour the production of water-based adhesives over solvent-containing products; however, this is not expected to have a major impact on the use of fillers.

Natural, elastomeric and most thermoplastic adhesives have reached maturity in their technical development. The major areas receiving attention are the hot-melt and structural adhesives, with a view to expanding their areas of application outside traditional use.

A number of developments have occurred in hot-melt adhesives [13,14]:

- Henkel (West Germany) has introduced high-purity Macromelt™ adhesives that are claimed to be stable at high temperatures.

TABLE 13-5 U.S. CONSUMPTION OF FILLERS IN CONSTRUCTION ADHESIVES

Product	Consumption (tons/year)
Kaolin	
air floated	14,000
water washed	3,000
Calcium carbonate	8,000
Others	500
Total	25,500

Source: ref. [12]

- Monsanto (U.S.) has introduced a range of structural hot-melt adhesives for bonding reinforced plastics. The materials are claimed to form strong bonds to a variety of substrates in as little as 30 seconds.
- Bostik (U.K.) developed reactive hot-melt polyurethanes with improved structural performance by cross linking. A number of these new hot-melt adhesives, not necessarily structural, are targeted at the construction sector.
- Komnerling offers a range of Koramelt™ hot-melt adhesives based on synthetic polymers and thermoplastic rubber for bonding insulation materials such as expanded polystyrene, polyethylene foam and rigid polyurethane foam.
- Evode (U.K.) has produced a range of thermospray, pressure sensitive, hot-melt, spray-applied adhesives which are claimed to replace many conventional adhesives in the construction and general industrial sectors. The adhesives are based on rubbers and tackifiers and are applied by spray gun or automated spray with a controlled thickness, in contrast to conventional bead application. A further advantage is the absence of damage due to the rapid drop in temperature of the adhesive material after it leaves the gun nozzle.
- Tivoli Kay Adhesives (U.K.) invested in the Tivomelt™ product range of EVA thermoplastic rubber based materials, the target markets being building construction.

Hot-melt adhesives do not usually contain fillers or extenders; thus, their growth does not present a significant opportunity to industrial minerals.

Structural adhesives continue to attract the highest R & D investment of all the adhesive types. The broad trend in the replacement of metals by engineering plastics, composites and ceramics has highlighted the need for high performance adhesives. To meet these challenges, new formulations and new resin chemistry are being developed. Toughening of rigid resins by the incorporation of dispersed rubbery materials continues to be the major avenue.

Paint

The manufacture of paints and coatings employs more different types of extenders, fillers and pigments than any other industry — over 40 different products are used, including nine grades of calcium carbonate and six grades of calcined kaolin. With the exception of pigments and minerals introduced to affect the gloss or flatness of finishes, most of these materials are incorporated to lower the cost of the final product. Mineral-based components account for ~40% of the weight, but only 5% of the cost, of raw materials for coatings. Titanium dioxide (TiO_2) pigment still remains the most important mineral product in paints. Typical use levels and key properties of the major mineral fillers used in paints are given in Tables 13-6 and 13-7, respectively.

A major trend over the past 5 years in the paint industry has been the continued development and application of water-based systems [15]. This was dictated by environmental regulations on the use of solvent-based paints. In response to the environmental regulations, there has been development of new technologies including powder coatings, water reducible systems, high solids and UV-cured systems. The manufacturing of these new coatings often

TABLE 13-6 TYPICAL FILLER LOADINGS IN PAINTS

Product	lb/100 gal.
Alumina hydrate	50–75
Barite	50–400
Calcium carbonate,	
ground	500–600
precipitated	200–300
Kaolin,	
calcined	50–250
delaminated	50–100
water washed	50–100
Mica	5–50
Silica,	
ground	50–250
pyrogenic	10–40
Talc	50–250

requires changes in formulation, manufacturing equipment and raw materials — for example, changes in dispersion equipment will promote the use of surface-coated pigments and fillers, including kaolins and calcium carbonates.

Among fillers and extenders, calcium carbonates are the main type used in paint formulations. The trend towards water-based paints gives calcium carbonates an advantage over talc fillers, these frequently being hydrophobic and requiring coating to render them dispersable. As paints become more sophisticated, coated and precipitated grades of calcium carbonate are being used [15].

Micronized mica is now widely included in emulsion paints with loadings of 10–20% to promote matt finishes, durability and anti-cracking features. An important function of mica in paints is the alignment of platelets parallel to the substrate. This both improves adhesion and inhibits the infiltration of water and deleterious dissolved ions such as chloride and sulphate into the film. Mica also produces an insulating barrier in fire-protection paints which retards the access of air for combustion; for this application, high aspect ratio grades are required. For aesthetic purposes, texturing can be provided in paints by using mica in the 3 mm to 100 mesh (0.149 mm) size range [17].

Silica flour and tripoli render paints resistant to acidic environments. They also improve tint retention, durability and flow. Fumed silica can be used as a thixotropic agent. As more coatings containing >70% solids are developed, opportunities will be created for rheology modifiers such as pyrogenic silica.

Both nepheline syenite and feldspar fillers are used in paints, particularly for the production of translucent or clear films. The refractive index of these materials is close to that of many organic paint media and a filled but transparent film becomes possible by selection of suitable grades of nepheline syenite or feldspar fillers . Both fillers are also valued as low tint-strength pigments where maximum colour development is achieved with small amounts of expensive colouring pigments [18].

In relation to pigmenting functions, the paint industry is the largest consumer of high whiteness filler grades of barite, with the primary function of providing opacity [19]. While TiO_2 remains a satisfactory pigment for attaining hiding power, the choice of non-hiding pigments to produce specific effects is being studied. Fillers such as kaolin and calcium carbonate are used in paints to substitute for expensive TiO_2 pigments. In this role, the trend towards water-based paints is expected to favour water-washed kaolin grades [20]. Among these auxiliary pigments and extenders, some have a slightly alkaline reaction in water-based systems, which is harmful. The materials may be treated or coated in such a manner as to introduce desirable properties such as good adhesion to the vehicle.

In more developmental areas, the concept of reinforcement is being introduced into the coatings field by the use of randomly oriented fibres to give greatly enhanced film-strength and other properties. Improved fire-retardant paints are needed, and coatings that can tolerate temperatures of 500°C continuously for long periods of time are desired.

Plastics

As noted earlier, while it is largely an issue of competition, increasing use of plastic-based building products also offers opportunities to the industrial minerals industry in the

TABLE 13-7 KEY PROPERTIES OF FUNCTIONAL MINERAL FILLERS FOR PAINT SYSTEMS

Filler	Particle Shape	Size (μm)*	Brightness (%)	Oil Absorption (wt %)	Specific Gravity	Refractive Index
Kaolin	plate	0.2–5	80–93	25–58	2.6	1.56
Calcium carbonate	rhomb	5–44	93–95	6–15	2.7	1.6
Talc	varies†	2.5–13	65–90	29–72	2.85	1.59
Asbestos§	fibre	—	85	40–90	2.5	1.5
Barytes	irregular	1–12	—	5–13	4.44	1.64
Mica**	plate	44–120	—	48	2.7	1.59
Attapulgite	needle	0.1‡	—	80–190¶	2.4	—
Diatomite	amorphous	4–8	—	130–170	2.2	1.45
Silica	irregular	1–5	85–91	22–32	2.6	1.55
Wollastonite	needle	3–8	84–93	26	2.9	—

* equivalent spherical diameter, microns; † may be lamellar, fibrous, or foliar; § chrysotile; ** muscovite; ‡ colloidal grades, agricultural grades are 95% less than 100–200 mesh; ¶ agricultural (sorptive grades).
Source: ref. [16]

production of mineral fillers and reinforcers. However, there is a general uncertainty over the distribution of plastic between construction and other applications; there is even less information available to permit an estimate to be made of the proportion of plastics that both contain fillers and may be counted as construction products. A recent report published by the Ontario Ministry of Natural Resources [21] estimated that 640,000 tonnes of fillers were consumed on average each year during the period 1980–1985 in the combined rubber and plastics industries. Consideration of the growth that has occurred in the plastics market and the construction sector suggests that this estimate is probably low in current terms.

Table 13-8 lists the major minerals used in different plastic resins and the function that they perform in finished plastic products. In general, though fillers were used originally in plastics largely to reduce materials costs, the modern plastics industry uses minerals for the functions that can be brought to the finished product. Some illustration of the various roles that different minerals perform in modern plastics is given in Table 13-9. The ranges of loading common in plastic products are given in Table 13-10. (Related information of the use of polymers and fillers in "polymer concrete" can be found in Chapter 10.)

As noted, PVC dominates the construction market for plastics (47%), being used mostly in flooring, pipes, siding,

TABLE 13-8 TYPICAL MINERAL FILLERS USED IN PLASTICS COMPOUNDING

Mineral	Major Resin	Function
Mica	Polypropylene	Flexural strength
Kaolin, surface treated	Nylon	Dimensional stability
Wollastonite	Nylon	Reinforcement
Alumina hydrate	PVC, polyester	Flame retardence
Calcium carbonate, pptd.	PVC	Impact strength
Kaolin, calcined	PVC	Electrical resistance
Talc	Polypropylene	Stiffness
Silica, ground	Epoxy	Dimensional stability
Calcium carbonate, ground	PVC	Cost reduction
Kaolin, air-floated	Polyester	Thixotropy

Source: ref. [10]

TABLE 13-9 INFLUENCE OF FUNCTIONAL FILLERS ON SOME PROPERTIES OF THERMOPLASTICS

	Asbestos	Wollast-onite	Mica	Talc	Silica	Kaolin	Glass Spheres
Tensile strength	+	..	+	0	..	..	+
Compressive strength	..	..	..	+	..	..	+
Modulus of elasticity	++	++	++	+	+	..	+
Impact strength	-	-	+/-	-	-	-	-
Reduced thermal expansion	+	..	+	+	+	+	..
Reduced shrinkage	+	+	+	+	+	+	+
Increased thermal conductivity	+	+	..	+	+	..	..
Increased heat deflection temperature	+	+	+	+	..	+	..
Electrical resistance	..	+	++	+	+	++	..
Thermal stability	..	+	+	+	+	+	..
Chemical resistance	+	+	+	0	..	+	+

Key: ++ considerable influence; + less pronounced influence; 0 no influence; - negative influence.
Source: ref. [16]

window frames and interior fixtures. In these functions it is used frequently in conjunction with fillers at loadings as high as 450 phr (parts per hundred parts resin), to give stiffness and dimensional stability. PVC pipe products account for 15–20% of the consumption of fillers in plastics, and vinyl flooring consumes a similarly large volume. Barite, carbonates, diatomite, calcined kaolin, wollastonite, and minor amounts of silica are the common fillers used in PVC building products. At one time, asbestos was a major component of vinyl floor tiles, but it has now largely been displaced in favour of other materials and improved resins.

Some examples of innovative plastic products, in development and current use, which will provide opportunities for the future are as follows [22,23]:

- Light transmitting plastics are replacing glass, making new construction products possible for indoor and outdoor use. An added bonus is the ability to design and shape plastic components to match their aesthetic environment.
- Rigid plastic profiles are becoming the material of choice for many components of residential and commercial buildings, e.g., vinyl sidings, window frames, trim and moulding, and new products are continually being introduced.
- Plastic fencing, offering good appearance and performance, is on the verge of achieving more widespread use in North America.
- Plastic roofing shingles, that look like cedar but outperform it, are now on the market.

Long-term growth of plastics in construction will occur through new ways of thinking, new materials and new methods. There is evidence that this is already occurring, as illustrated by examples of leading-edge developments [3]:

- A three-dimensional woven wall panel developed in Japan is a remarkable departure from using solid materials. In this product, a large open-cell panel is woven from fibres of glass, carbon or Kevlar, and is bonded with epoxy resin. It is lightweight, can be clad with a variety of outside facings, and may be filled if desired. Typical commercial applications include curtain walls, corrosion resistant seawalls, and similar structures.
- Another new concept is plastic fire-stop tape that expands in the presence of fire creating a barrier to the spread of fire. The "intumescent" tape is wrapped around pipe locations where pipe passes from one storey to the next. The tape is far easier to install than the heavy metal-fitted collars currently used.
- Plastic composite beams have been developed that are reported to be superior to steel I-beams in terms of cost/performance. The beams are made of filament-wound fibre-reinforced plastic (FRP) that is foam-filled and provides rigidity, high strength, and light weight.
- FRP rebar for prestressed concrete beams is becoming available and is beginning to be used in bridge construction in Germany. The rebar is made in a continuous "pultrusion" process and provides excellent resistance to corrosion.
- Flame-resistant foam insulation has been invented to address the safety requirements of commercial and industrial buildings.
- General Electric Plastics is scheduled to build its "Living Environments Concept" house to serve as a laboratory to investigate advanced materials and new methods of building and construction. The "Living Environments" program is expected to demonstrate the full capabilities of engineering plastics in challenging wood, glass, stone and steel materials traditionally associated with house building.

TABLE 13-10 TYPICAL FILLER LOADINGS IN PLASTICS

Product	phr*
Alumina Hydrate	5–150
Barite	2–5
Calcium Carbonate	40–450
Kaolin	5–275
Mica	40–150
Silica	5–60
Talc	5–40
Wollastonite	5–15
Titanium dioxide	10–40

* parts per hundred-parts of resin

Calcium carbonate in one form or another is reported to hold ~70-75% of the plastics fillers market in both Europe and North America [24]. Calcium carbonate fillers have seen major growth in all areas, one contributing factor being the expanded use of PVC pipe in construction (Table 13-11). Though the data in this table are out of date by 10 years, they serve to illustrate the versatility of carbonate fillers in the plastics industry.

In most applications, mica is used in plastics to provide some reinforcement and to give dimensional stability to the polymer. The main properties conferred by mica are: a significant increase in tensile and flexural modulus and strength, along with a decrease in elongation; a reduction in thermal expansion and warpage; increased resistance to heat distortion; increased impermeability to liquids and gases; inertness to UV light and chemicals; and improved dielectric properties.

Both muscovite and phlogopite micas are used, the latter being selected when colour is less important. At the present time, mica is used mostly in the automotive industry and for high performance engineering plastics. Consumption in construction plastics is probably small, though no data have been found to confirm this view.

The principal use for kaolin in plastics is in PVC coatings for electrical cables, largely because of the electrical resistance that it imparts. In other applications, kaolin is used to impart impact resistance, gloss, stiffness, or brittleness, and as an extender for TiO_2. Silica flour and tripoli are used to impart flexural and compressive strength, dimensional stability and shock-resistance, to plastics. Their low

TABLE 13-11 APPLICATIONS FOR CALCIUM CARBONATE FILLERS IN PLASTICS

Polymer	Filler Level (phr)	Particle Size (μm)	Remarks
Flexible PVC	20–60	3	Compared with coarser grades, fine fillers cause less of a decrease in physical properties and provide better performance in thinner calendered films and coatings.
PVC plastisols and organisols	20–100	wide range	Coarse grades for carpet backings, to ultra-fine precipitated grades and coated chalk whiting for thixotropic viscosity control. Coarse particles lead to lower viscosity in plastisols.
Rigid PVC	1–5	40	Used in plastic pipe for potable water.
	40	1–3	Other pipe and conduit applications. Stearate-coated grades improve melt rheology and smoothness of extrusion; uncoated grades serve as anti-plate-out agents.
PVC floor tile	8–400	small	Finest grade is ~12 μm, size distribution is wide, colour varies with feedstock.
Sheet moulding compound	200	3–6	Used in low viscosity 1- and 2-component resins. Moisture content must be kept below 0.1% for controlled thickening during maturing.
Bulk moulding compound	250	3–6	Loadings are usually 250 phr for BMC, 100–150 phr for premix, preform, and mat (over 400 phr is possible). Size distribution and purity are selected to provide low uniform viscosity polyester.
Marine polyester	175–200	3–5	Meets standard requirements for this application of 0.15% max. water absorption during a 24-hr immersion.
Polypropylene	43–67	1–3	For both polypropylene homopolymer and copolymer.

Source: ref. [25]

oil absorption and good wetting properties permit rapid dispersion and high loading in many composites. One problem with silica fillers is the wear that they cause on extrusion and moulding equipment. It has been suggested that the availability of finer grades may overcome this drawback [25].

Both nepheline syenite and feldspar are used in plastics over a wide range of applications. Particularly relevant to construction applications are high-traffic vinyl floor tiles, PVC coving, polyacrylate corrugated roofing, and polyester building facades. Many of the properties that make these minerals useful in paints are also valued in plastics. Especially important are low oil absorption, low viscosity at high loadings, high dry brightness, low tint strength, and stain and abrasion resistance. Like silica, nepheline syenite and feldspar fillers are useful for chemical resistance. The index of refraction match of nepheline syenite with common vinyl resins (1.53) means that it can be used as a filler in transparent plastics. Corrugated roofing is an example where exceptionally high loadings can be attained while obtaining a translucent and chemically resistant product. As is the case for paints, micronized nepheline syenite has been creating interest for applications as a low cost filler in PVC [18].

INDUSTRIAL MINERAL FILLERS

While the consumption of mineral fillers by polymer-based products is dominant in modern practice, they are also used in a wide range of other building products (Table 13-12). From the technical perspective, fillers are judged by a number of characteristic properties, some key examples of which are given in Table 13-13. Consistency of properties is generally an overriding concern in the use of fillers. In some applications, fillers may constitute more than 50% of the final product. In such cases, variations in properties such as colour or particle size could have major impact on the acceptability of the filler.

Fillers, extenders and reinforcing agents can be made from a wide variety of materials, not all of mineral origin. However, the best known are produced from naturally-occurring minerals such as kaolin, calcite, talc, mica, silica and asbestos. Fillers may be produced also from organic materials such as plastic beads, or they may be manufactured from glass, metals or ceramic compositions. Fibrous reinforcements may be obtained from wood, cellulose or synthetic products such as plastics, glass or mineral wool. However, most of the fillers used in building products are derived in some way from industrial minerals.

Estimates of filler consumption in North America in 1983 (Table 13-14), though now dated, serve to illustrate the relative importance of the principal filler types and the general product areas in which they are used. Kaolin and calcium carbonate supply the major portion of the filler requirements, with most of the kaolin products going to the paper industry. On this basis, calcium carbonate fillers, a large portion of which are used in plastic products, may be assumed to be the dominant type used in building materials.

A number of other minerals — for example, diatomite, nepheline syenite, gypsum, bentonite, serpentine, and attapulgite — play relatively minor roles in the filler and reinforcement market. Also in this category are mineral-

TABLE 13-12 RANGE OF APPLICATIONS FOR MINERAL FILLERS IN BUILDING PRODUCTS

Application	Type of Filler Used
Asbestos cement and other cement-board products	Asbestos, calcium carbonate, mica, glass and mineral wool, vermiculite, wollastonite
Asphalt products	Calcium carbonate, talc, mica, glass fibre
Brick, blocks, concrete products (incl. polymer concrete)	Asbestos, calcium carbonate, mica, glass and mineral wool, vermiculite, perlite, wollastonite, diatomite, silica, fly ash
Putty, caulking, sealants, adhesives, drywall compounds	Calcium carbonate, talc, silica, mica, kaolin, wollastonite
Floor tile	Calcium carbonate, talc, mica, kaolin, wollastonite
Plastics and paints	Calcium carbonate, talc, silica, mica, kaolin, wollastonite, barite, nepheline syenite, diatomite
Rubber	Calcium carbonate, talc, mica, kaolin, precipitated silica, barite

based products manufactured by thermal or chemical treatment which can be classed as synthetic fillers. These include expanded vermiculite and perlite, used as low density fillers and aggregates; precipitated and fumed (pyrogenic) silicas; calcium sulphate fibres; aluminum trihydrate; and various glass or ceramic microspheres. Synthetic reinforcers include glass, mineral wool, ceramic fibres, and synthetic wollastonite.

THE ONTARIO MINERAL FILLERS INDUSTRY

In 1984, the Ontario Ministry of Natural Resources (MNR) published a study by Guillet and Kriens [21] of the availability, production and markets for minerals as fillers in a "study area" comprising Ontario and the immediately surrounding regions of Canada and the U.S.A. (Fig. 13-3). This study area was selected as being both within the general potential market region for materials produced in Ontario and containing potential supplies of fillers for users in Ontario. The minerals considered were the principal fillers used in paper and polymeric products: namely, barite, carbonates, kaolin, mica, silica and talc. The findings from this study are particularly relevant in our examination of the potential for Ontario filler and extender minerals in construction products.

The mineral fillers industry in Ontario comprises a mixture of processors of industrial minerals, and suppliers of finished filler products from imported sources. Carbonates, talc, silica, nepheline syenite, serpentine and barite fillers are all produced commercially in Ontario, while kaolin, chrysotile asbestos, wollastonite and other mineral fillers are all currently supplied by imports from other provinces, the United States, or abroad. Chemically-produced fillers

TABLE 13-13 KEY PHYSICAL PROPERTIES OF MINERAL FILLERS

Mineral	Particle Size (avg. μm)	Surface Area (m^2/g)	Specific Gravity	Aspect Ratio	Moh's Hardness
Calcium carbonate,					
ground	5–15	1–5	2.7	low	3–3.5
precipitated	0.1–1	5–20	2.6	low	2.5–3
Hollow glass beads	50–75	n/a	0.1–0.7	low	5–6
Alumina hydrate	1–1.5	5	2.4	low	2–3
Kaolin	0.2–1	10–20	2.6	moderate	2–2.5
Mica	n/a	30	2.8	high	2–2.5
Silica, ground	2–6	1–2	2.65	low	7.5
Silica, fumed	0.04–0.05	50–150	1.8–2.2	low	n/a
Talc	1–1.5	6–10	2.8	moderate	1.5
Wollastonite	n/a	1	2.9	high	4.5–5

Source: ref. [10]

TABLE 13-14 ESTIMATED ANNUAL U.S. CONSUMPTION ('000 TONS) OF MAJOR CATEGORIES OF MINERAL FILLERS (1983)

Minerals	Product Applications					
	Paper	Paint	Plastics	Rubber	Other	Total
Kaolin	3,430	200	90	350	160	4,230
Calcium carbonate	300	330	400	120	1,100	2,250
Talc	90	170	60	40	80	440
Silica	15	90	20	50	10	185
Alumina hydrate	20	minor	80	5	50	155
Mica	minor	25	10	5	70	110
All other	25	135	40	5	25	230
Total	3,880	950	700	575	1,495	7,600

Source: ref. [12]

are mostly imported. Among reinforcing agents, synthetic glass and mineral wool fibres are produced in the province. (These are discussed with other glass products in Chapter 12.)

Filler minerals are not considered separately from other industrial mineral products in compilations of statistical data. Thus, except in a few cases where the mineral is principally used as a filler, there is a lack of production and consumption data on which to base a description of the industry. In the MNR study, Guillet and Kriens developed estimates of consumption on the basis of production data for manufactured end products known to incorporate various filler types [21]. This gives a valuable picture of the industry as a whole, but because data on production of most manufactured goods do not indicate the quantity specifically produced as building materials, this approach results in an incorrect estimate of the use of fillers in building products. For these reasons, the filler minerals are considered as products supplied to a broad range of users, with little differentiation possible between their use in building products and in other applications. Such an approach is probably justified because any producer of fillers would supply a range of users rather than specializing in providing materials only for building product applications.

Significant quantities of filler minerals are used in non-filler applications; however, the data show the general position with respect to importation and provincial production of minerals that hold a key position in filler manufacturing. A more exact estimate for Ontario is available from the data given in the MNR report [21] as it relates to the study area (Table 13-16).

IMPORTED MINERAL FILLERS

The following mineral fillers, extenders and reinforcing agents are not currently produced from native resources in Ontario:

- Kaolin
- Vermiculite
- Diatomite
- Mica
- Perlite
- Alumina trihydrate
- Wollastonite
- Attapulgite
- Bentonite
- Calcium sulphates
- Chrysotile

Figure 13-3 Study area for estimation of filler market in Ontario. Source: ref. (21).

All of the supply of these fillers is imported from other provinces or abroad. In some cases, unworked deposits of the minerals from which these fillers are produced are known in Ontario. Of particular note in this respect are the kaolin, mica, wollastonite and calcium sulphate products.

DEVELOPMENTS IN MINERAL FILLERS

The principal technical developments affecting fillers and reinforcing agents in a broad range of applications have been designed to improve their compatibility and performance in composites. Consequently, some commodity minerals can become specialty additives and command higher prices by reason of their having been upgraded through micronizing, air flotation, or chemical modification. Because use in polymer systems is such an important market for most fillers, producers have, in recent years, paid special attention to the needs of this consuming sector. In particular, two trends have developed: a trend to produce finer grades; and a trend to offer chemically-modified grades to encourage filler/resin interactions that enhance modulus, impact and tensile strength in composites.

Chemically-treated minerals represent the highest value-added segment of the industrial minerals industry. Depending on the mineral properties and the specific application, the cost of chemical modification can add from 7 cents to $1 per kg to the cost of the mineral [10]. A summary of the applications of modified fillers in the plastics and rubber industries is shown in Table 13-15.

Mineral surface modifiers, which are used to make fillers more compatible with polymer resins, can be classified into four groups:

- *Silanes* are true coupling agents which possess an organic and an inorganic functional group. They are used primarily to treat silicate-type fillers.
- *Stearate* treatments (predominantly stearic acid and calcium stearate) are used to modify acid-reactive fillers. They are particularly effective in improving wetting and dispersion of calcium carbonate fillers in composites.
- *Organometallic* compounds, including zinc-aluminates and titanates, are intermediate between wetting and coupling agents. They are effective for both siliceous and carbonate materials, and are compatible with the full range of thermoplastic and thermoset polymer systems.
- *Wetting agents* for treatment of fillers include polymeric esters, chlorinated paraffins and polymerizable cellulose materials. Wetting agents aid in dispersing the filler, allowing for increased loadings, especially in polyester resin systems.

Chemical treatments impart different properties to the fillers which must be chosen according to the requirements of the resin system and the product being manufactured. For example, rigid PVC compounds, of the type used in siding or window frames, require good filler dispersion and relatively

TABLE 13-15 PRINCIPAL APPLICATIONS AND PROPERTIES OF MAJOR CHEMICALLY-MODIFIED MINERALS

Product	Major Application	Function
Alumina hydrate	Wire and cable PVC and EPDM	Flame retardence, processing properties
Calcium carbonate	PVC pipe	Higher loadings
Kaolin	Tire products EPDM, wire and cable	Pigment replacement, electrical properties
Wollastonite	Nylon	Physical properties, glass replacement
Microspheres	Nylon	Physical properties
Mica	Polyolefins	Physical properties
Fumed silica	Silicone rubber	Processing
Ground silica	Epoxy moulding compounds	Electrical properties
Talc	Industrial rubber	Physical properties
Organophilic clays	Coatings	Rheological properties

Source: ref. [10]

high filler loading levels, which is usually accomplished with stearates and wetting agents. In contrast, nylon compounds, frequently used in door and window hardware, require stiffness and impact strength, which may be accomplished with filler coupling agents.

The use of chemically-treated mineral fillers in the United States was estimated to be 166,000 tonnes in 1984, with a value approaching $110-million (U.S.); comparable data, however, are not available for Canada [10]. Much of this was stearate-treated calcium carbonate, pretreated by the producer. Silane and organometallic treatments were carried out by both filler producers and plastics compounders, on such minerals as silica, kaolin, wollastonite and bentonite. Approximately 55% of chemically-modified filler was calcium carbonate used in PVC pipe [10].

Reports from Kline and Co. [10] anticipate that treated minerals will be a major contributor to growth of new composite technology in the next few years. It should be noted, however, that only a small and indeterminate fraction of the materials in which these filler products are used are employed in the construction of buildings. Much of the projected growth will come from the high-technology end of the market, through applications in industries such as automobiles and aerospace.

PROSPECTS FOR INDUSTRIAL MINERALS

The opportunities for industrial minerals in the fillers field have, for some time, been good. Fillers and reinforcing agents have wide applicability beyond their use in building materials. This broad market base supports the substantial investment required to produce high value-added products, and makes the effects of the cyclical activity of industries such as construction less of an influence on the filler supplier.

Technical opportunities for industrial minerals in the construction products field are arising as follows:

- The growth of plastics in construction will necessarily extend the market size for fillers or reinforcers.
- The increasing demands on the performance of plastic products in buildings will cause a corresponding demand for better filler performance. Finer-sized and chemically-coated products will be required, both of which increase substantially the added value for the producer.
- The search for substitutes for asbestos in building products, and for better fibres for use in cement-based composites will continue. If the industrial minerals industry enters into research and development to meet these needs, new product opportunities will follow. (See also Chapter 14.)
- Specific opportunities are to be found in development of known resources, such as wollastonite for fibres, mica and kaolin for filler applications, and gypsum for chemically-precipitated filler and fibre products. Opportunities also exist for the production of synthetic wollastonite.

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14. Alternatives to Asbestos

- Mica
- Vermiculite
- Perlite
- Talc
- Pyrophyllite
- Wollastonite
- (Clays)
- (Glass fibre)
- (Mineral wool)

The term *asbestos*, as it has been applied in industry and technology, refers to a number of fibrous (asbestiform) minerals of two general types: *chrysotile*, a serpentine mineral, and a group of amphiboles, of which *crocidolite* and *amosite* are the most widely used. For many years, these minerals were of major commercial importance in the manufacture and properties of four classes of products:

- construction materials
- friction products
- heat-resistant fabrics
- reinforced plastics

Among construction materials, asbestos-cement products, some types of insulation, roofing shingles, floor tiles, sealants and jointing compounds were the principal end uses for industrial asbestos, most of which was chrysotile. In recent years, health and safety concerns regarding exposure to asbestos fibres have lead to the virtual elimination of asbestos from many of its previous applications.

Although Canada has major deposits of chrysotile and has been a principal supplier of fibre, none is produced from sources in Ontario. The major construction use for asbestos fibres has been in so-called asbestos-cement (AC) products, notably board and pipe. While both products continue to find some use in the province, all sources of supply are in Quebec, British Columbia or abroad. Three North American companies produce AC products: Atlas Pipe in Montreal and Mission, B.C.; and Certainteed and CAPCO in the United States.

Chrysotile asbestos was first used as a commercial material in the 1860s. As early as 1898, authorities in Britain reported that working with asbestos was a demonstrable cause of health problems, with bronchial and lung diseases being prevalent. By 1930, the disease known as *asbestosis* had been recognized, and in the early 1960s, malignant mesothelioma of the chest lining and peritoneal mesothelioma were both attributed to asbestos exposure [1].

Although the major concern originally focused on workers exposed to large doses of asbestos, other members of the households of asbestos workers were subsequently found to develop disease from dust brought home on clothing. Disease was also discovered in people living in the vicinity of asbestos mines and factories, and in people living in districts where the soil was rich in fibre. Concern has now extended to exposure to asbestos in buildings where the fibres have been used in various materials of construction, to the point that removal of asbestos has become a major and expensive procedure in many public structures such as schools, hospitals and airport terminals. By 1982, the Manville Corporation, a major supplier of asbestos, filed for bankruptcy and reorganization. The company had 25,000 employees and assets of $2-billion. It took this step to protect itself and deal with 16,000 lawsuits, including some from building occupants [2].

Partly as a consequence of the concerns over safety and health and partly for economic reasons, demand for asbestos started to decline steadily and drastically in 1979. This was particularly noted by Canadian producers (Fig. 14-1), much of whose production was traditionally shipped for use in North America and Europe [3].

Regulatory pressure to discontinue the use of asbestos in building materials is substantial in much of the world, especially North America and Europe. The report of the U.K. Advisory Committee on Asbestos [4], published in 1979, offered the following recommendation on the use of asbestos:

> "... we recommend that an explicit obligation should be placed on any person who produces specifications for or carries on a process involving the use of asbestos or any product containing it to consider the substitution of asbestos by other materials so far as it is reasonably practical to do so."

This type of approach has led to major efforts to find both substitute materials for asbestos, and substitute products for those which previously depended on asbestos for their production or performance.

This chapter examines the specific advantages offered to Ontario's industrial minerals products resulting from the need to find raw materials to substitute for asbestos for use in construction. In discussing this subject, related and important issues that are not specific to construction materials or industrial minerals have not been treated in depth. For a more complete consideration of these topics and the whole question of asbestos substitution, the reader is referred to a number of recent texts [1,5-8] and, in particular, to Hodgson's text, "Alternatives to Asbestos and Asbestos Products [6]."

ALTERNATIVE RAW MATERIALS

The physical and chemical properties of asbestos have been widely reviewed and need not be reconsidered in this report [8,9]. In general terms, asbestos, and in particular chrysotile, has properties of fibre length, flexibility, strength and heat resistance that make it unequalled by most other synthetic or natural fibres or minerals. Chrysotile is chemically resistant to alkalis, rendering it valuable in systems based on Portland cement and calcium silicate. However, it is not resistant to acids, this being one of its few technical limitations. It has unique surface properties that enable it to absorb resins, polymers and other organic chemicals, while also having the capacity to retain and support fine particles of cement in water suspensions. Given its long history of use, the close relationship between processing practice and its properties, and its wide range of applications, it is most unlikely that a single substitute will be found for asbestos in all of its previous applications. Industry, then, must settle for a range of substitutes, each meeting the needs of a few, specific end-products.

Substitutes must encompass these properties:

- fibrous form or other means of reinforcement in composites
- heat resistance
- compatibility with binders such as polymers or Portland cement

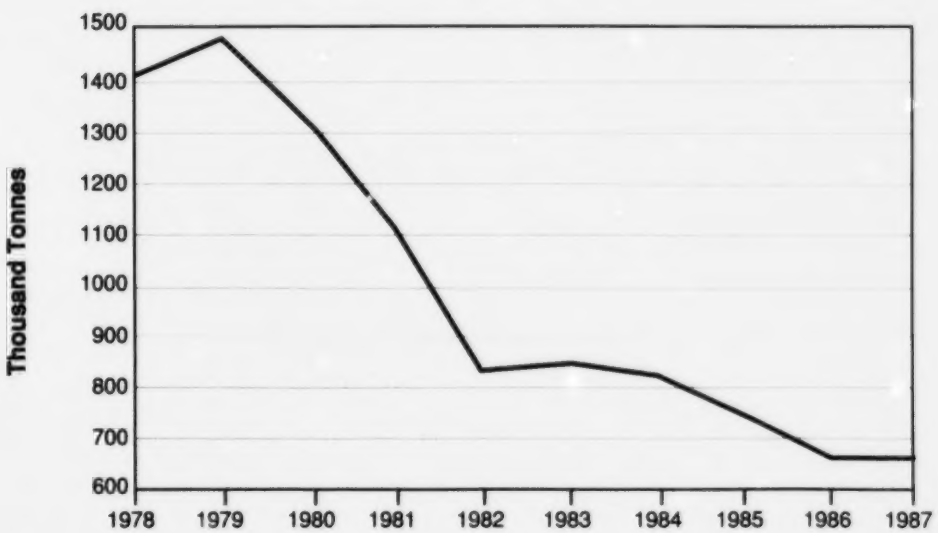

Fig. 14-1 Canadian shipments of asbestos, 1978-87. Source: ref. (3).

The potential substitutes offering some of these properties can be expected to be found among four types of materials:

- man-made mineral fibres
- minerals
- synthetic organic fibres
- natural organic fibres

Of these, only the two mineral-based fibres are of concern in the context of this report. Opportunities for industrial minerals can be found in (a) the manufacture of glass, mineral wool and refractory fibres, and (b) the provision of mineral substitutes.

Glass, Mineral Wool and Refractory Fibres

Glass, mineral wool and refractory fibres form a group of man-made mineral fibres that come closest to having comparable properties to natural asbestos. There are, however, some major limitations: for example, glass and mineral wool fibres are not resistant to alkalis, and most refractory fibres are not as flexible as asbestos.

In the area of building products, mineral wool and glass fibres have completely replaced asbestos in thermal insulation for buildings. In new products, the competition in these applications is now between cellular plastic and mineral-based insulation products. In vinyl floor tiles, asbestos has the advantage of providing wear and non-slip properties, whereas the use of glass or mineral wool tends to result in a brittle product with poor anti-slip qualities. Because of difficulties in replacing asbestos in vinyl tile, this has become an application where new products have been developed, based on superior vinyl polymer properties that do not require reinforcement. Thus, in two major areas in which asbestos once was an important building material, solutions to the problems raised by its hazardous properties have been found. Most of the recent development activity relevant to construction products has been concentrated on obtaining substitute reinforcement for cement- and calcium silicate-based composites. The emphasis has been on finding ways to render glass fibres alkali resistant, either through adjusting the chemical composition of the glass melt, or by applying coatings to the fibres.

Glass fibres are manufactured in a range of compositions, including E-, S- and A-glass (Table 14-1). While fibres from each type generally have good mechanical properties, they are unable to withstand chemical attack from the alkaline media of cement-based systems; thus, after a relatively short time in Portland cement or autoclaved calcium silicate products, the fibres lose a substantial proportion of their strength, and a weakened composite results. Among many attempts to formulate alkali-resistant (AR) glasses, the more successful have included the use of zirconia (ZrO_2) or thoria (ThO_2) in the melts. Although some success has been achieved through this approach, Hodgson has commented [6]: "The available evidence on mechanical properties ... does not provide any confidence that these products can satisfactorily replace asbestos or asbestos cement."

The compositions of a number of glasses claimed to be alkali-resistant are shown in Table 14-2. According to Hodgson, none of these are fully alkali-resistant, and all suffer some degradation in GFRC systems (see Chapter 10). Mackenzie [10] has reported that mixtures of Vermont slate and limestone can be used to prepare glasses which show almost as much alkali-resistance as chrysotile. Clearly, although research and development is required, a number of opportunities arise for the use of industrial minerals if effective alkali-resistant glass fibres can be produced. The approaches reported to date would indicate that, in addition to the normal glass-making raw materials (Chapter 12), opportunities may exist in this field for zirconia, fluorite, and various rare earth oxides. Though additions of these compounds or minerals to individual glass melts would be small, the potential market for alkali-resistant glass for use in reinforced cement, concrete and calcium silicate products is large.

TABLE 14-1 COMPOSITION OF SOME CONTINUOUS-FILAMENT GLASSES

Component Oxide	A-glass	E-glass	C-glass	AR-glass	S-glass
SiO_2	72.0	54.3	64.6	60.9	65.0
Al_2O_3/Fe_2O_3	0.6	15.2	4.1	0.3	25.0
CaO	10.0	17.3	13.4	4.8	..
MgO	4.7	3.3	0.1	10.0	..
Na_2O	14.0	0.6	7.9	14.3	..
K_2O	..	..	1.7	..	..
B_2O_3	..	8.0	4.7	..	..
BaO	..	..	0.9	..	..
TiO_2	..	..	..	6.5	..
ZrO_2	..	5.0	..	10.2	..

Source: ref. [6]

Mineral wool fibres are normally made from waste materials rather than from natural minerals, blast furnace slag being the most common source. Rocks such as basalt and diabase are generally used when slag is not available. Mineral wool generally has poor alkali resistance, but does show good filtration properties in the conventional asbestos-cement processes. It is reported that some improvement in alkali resistance can be achieved by making zirconia-based mineral wools [11]. This would suggest a potential use for sands rich in zirconia as additives to the normal blast furnace slag melts.

Ceramic or refractory fibres were not developed to compete with asbestos, but rather to complement it at higher temperatures. As well, they are generally expensive and are thus economically useful in only a few applications. Refractory fibres of the following types are available commercially [6]:

- silica
- alumino-silicate
- silicon nitride
- alumino-silicate-zirconia
- alumina
- boron nitride
- silicon carbide
- alumino-silicate-chromia
- zirconia
- boron carbide
- alumino-silicate-boria

Though it is outside the scope of comment of this report, the manufacture of such materials clearly offers opportunities to the industrial minerals producers.

Mineral Substitutes for Asbestos

Minerals used to replace asbestos are of two types: (a) those of fibrous or acicular form which have some potential to provide reinforcement in composites; and (b) those which provide reinforcing or thermal resistance values through other properties. In most cases, as with other replacements, minerals offer substitution capability for asbestos in only a limited range of applications, each of which must be considered uniquely. The minerals or mineral-based materials that have been used or proposed for asbestos substitution include:

- micas, vermiculite, perlite
- talc, pyrophyllite, wollastonite
- clay minerals — attapulgite, sepiolite and palygorskite

None of these exhibits the primary properties of asbestos: i.e. flexibility, fibre length, and compatibility with a broad range of matrix types; however, individually, they do possess valuable properties, such as light weight, thermal and chemical resistance and thermal insulation capability (Table 14-3). They are particularly useful in providing these properties when used in conjunction with organic fibres for replacing asbestos in reinforced cement boards (see below). Other aspects of the use of these minerals as fillers in polymer systems can be found in Chapter 13, together with information on their production or availability in Ontario.

TABLE 14-2 COMPOSITION OF SOME EXPERIMENTAL ALKALI-RESISTANT GLASSES

Component Oxide	Glass 1	Glass 2	Glass 3
SiO_2	49.6	28.7	28.0
Al_2O_3	1.5	23.4	22.9
Fe_2O_3	0.7	..	..
CaO	17.9	13.2	12.9
MgO	..	2.9	2.8
Na_2O/K_2O	9.0	2.9	2.5
MnO	..	12.0	11.8
B_2O_3	3.0	..	..
ZrO_2	17.0	5.1	5.0
TiO_2	..	5.0	10.0
CaF_2	0.8	..	..
La_2O_3	..	..	1.0
SnO_2	..	..	1.0
Melting Point (°C)	1450	1400	1400

Source: ref [6]

TABLE 14-3 CHARACTERISTIC PROPERTIES OF POTENTIAL ASBESTOS SUBSTITUTE MINERALS

Mica:
In cement-based composites, mica has good compatibility in both Portland and autoclaved systems, to which it brings the thermal insulation properties of asbestos. However, in the brittle matrix of cement systems, mica shows little reinforcing value; another form of reinforcement such as cellulose is usually required if board products are to be made (see below). This is in contrast to its reinforcing value in plastic composites.

Vermiculite:
Vermiculite is one of a number of minerals that expand (or exfoliate) when heated rapidly. In the exfoliated form, vermiculite can have a density of less than 100 $kg.m^{-3}$ and is an excellent thermal and acoustic insulator, either as loose fill or incorporated with other materials. It is used with cements to manufacture lightweight insulation boards and fireproof mixes, and it has largely replaced the use of asbestos in the sprayed-up type of mixes. Non-combustible composites can also be produced from foamed vermiculite in a sodium silicate matrix.

The thermal properties of vermiculite favour its use in insulating functions, but it does not possess the superior thermal resistance of chrysotile asbestos at high temperatures. In common with mica, vermiculite does not bring reinforcing properties to inorganic cement composites. As a substitute product, vermiculite largely functions to meet the thermal insulation capacity of chrysotile asbestos, requiring the use of other materials in products where reinforcement is needed.

An interesting application for vermiculite is the potential for preparing chemically-modified material to be applied as coatings to alkali resistant glass fibre. More details of this process are given in Chapter 15 in relation to more general considerations of the chemical modification of minerals.

Perlite:
Another rock that can be expanded to a low density form is perlite. The construction industry accounts for the use of 60–70% of perlite-derived low density aggregate in cement and gypsum products, insulating boards, or as loose fill insulation. In these functions, perlite has always either competed with or supplemented the use of asbestos. Like mica and vermiculite, perlite provides thermal insulation without offering reinforcement in inorganic cemented systems.

Talc and Pyrophyllite:
Talc is used in many engineering plastics where reinforcing characteristics are often attributed to it (Fig. 14-2). It is not, however, an important alternative to asbestos except for replacement of the shortest grades in floor tiles and some paints. Pyrophyllite, which might be loosely regarded as an aluminum analogue of talc, has high temperature properties that give it applications that are competitive with the capabilities of asbestos in some refractory materials. In this role, pyrophyllite could be considered as an alternative to asbestos as a high temperature component of fire-resistant panels or insulation materials. Similarly, micas with their platy habit are widely used to improve flexural and impact strength in composites.

Wollastonite:
The mineral most closely able to simulate some of the reinforcing value of asbestos is wollastonite. By careful jet-milling, wollastonite can be produced as acicular particles with aspect ratios of up to 20:1 and particle diameters of the order of 1 μm. Wollastonite is a relatively rare mineral in commercial quality, some deposits of which are under consideration in the province.

The mineral has its main uses as a filler in plastics, ceramics and insulating materials. It has been proposed as an alternative to asbestos in insulating materials and wallboards, and as a reinforcement in heat-resistant cement. While it has its main applications in ceramics, plastics, abrasives, paints and insulation, wollastonite has been suggested for use in wallboards, floor tiles and asphalt emulsion coatings [6,12]. The fibres have also been investigated for uses in glass-ceramic compositions [13], building boards [14], non-flammable paper for wallboard [15] and high-strength cement products [16].

In addition to its natural occurrence, wollastonite can be synthesized from its component oxides (i.e. CaO and SiO_2) by sintering at ~1500°C [6]. A Japanese process for producing fibrous wollastonite from a glass composition by using glass-making methods has been patented [17]. Other processes are available through patented technology [18].

Continued

Clay minerals:
Several clay minerals are finding applications in the asbestos substitution area, the most notable being three hormites — palygorskite, sepiolite and attapulgite — and halloysite (a kaolinite). The main features of interest in these minerals are their fibrous habit and high surface area.

The hormites have a range of applications as fillers and viscosity modifiers in polymer-based products (see Chapter 13). In general, these minerals do not exhibit reinforcing properties, but they have other attributes in common with asbestos: for example, sepiolite and attapulgite can provide filtration and rheological control in the production of cement systems reinforced with synthetic organic fibres; sepiolite may also be used to give thixotropy in bituminous sealants and drywall jointing compounds, both functions previously attributed to asbestos grades; and palygorskite and attapulgite and have been used to replace short asbestos fibres in floor tiles.

Halloysite is one of the kaolinite minerals that, as a consequence of its degree of hydration, has a stacking fault that results in the formation of a fibrous rather than platy morphology. There have been reports from Japan that halloysite is a possible alternative to asbestos in the development of fire-resistant building products [6].

ALTERNATIVE PRODUCTS

The difficulties associated with finding materials that match or substitute for the properties of asbestos have forced the alternative product approach — that is, the development of products that contain no asbestos, but perform the functions of established asbestos-containing building materials.

As we have seen, there is little difficulty in matching the insulating character of asbestos, except at temperatures that are sufficiently high as not to be generally applicable in buildings. Glass and mineral wool fibres, mica, vermiculite and perlite are all available for these functions. It is in the area of reinforcement, and particularly the reinforcement of inorganic cemented systems, that the main problems occur. The issue is essentially one of finding forms of fibrous, non-asbestos reinforcement that are compatible with the properties of the matrix materials used in construction composites — or conversely, finding new matrix materials that do not cause degradation in normal glass or mineral wool fibres.

Two general types of fibre-reinforced composites are used in construction materials: those in which the matrix is an organic polymer, and those in which the matrix is an inorganic cement. The differences are fundamental in a number of ways relating to the interaction of the fibres with the matrix and the type of mechanical properties desired.

There are three basic elements in fibre-reinforcement: the fibre, the matrix, and the fibre-matrix interface. Each must have appropriate characteristics, and function both singly and collectively for the composite to perform in service. In polymer-matrix composites, the matrix is usually ductile, but lacks stiffness and tensile strength. Under stress, it elongates and deforms, until finally, failure occurs after considerable distortion of the structure. Impact may not break the polymer, but it will distort it and damage any surface characteristics. In such a matrix, the role of fibres is to increase tensile strength, by transmitting the stresses from the matrix onto the fibre, and at the same time, to increase stiffness or resistance to distortion by reducing the tendency of the matrix to flow. The result is a stiff, but not brittle, strong product, such as a well-made glass-reinforced panel that can sustain reasonable impact without permanent damage and can support the flexural or tensile loads required in service. To attain this, the fibre used should have a high tensile strength and modulus (stiffness), be compatible with the polymer so that it can be dispersed and wetted during fabrication, and maintain a bond at the surface between polymer and fibre, such that transfer of stress is effective. Other properties are important in the final choice of fibres, including thermal stability, size, flexibility and cost. In general, these properties are provided adequately by various forms of glass fibre; in some cases, the use of asbestos was desirable for specific reasons such as the non-slip character that it gives to vinyl tile. In any case, overall, the unavailability of asbestos in the polymer field has relatively little impact on the building materials end of the polymer composites market where fillers and glass fibre have dominated for some time.

The situation is different in brittle matrix composites. Most cementitious matrices are strong in compression and stiff enough for service conditions. The problems lie in their poor performance under tension — or, as is more often experienced in buildings, under flexure, impact or shearing forces. Under tension, brittle matrices rapidly reach failure load with little distortion — that is, their modulus is high. Because of the low elongation at rupture of the matrix, separation of the element is catastrophic; it breaks over a small increase in stress, and usually the broken parts cannot support any load: the material lacks toughness and ductility. The situation may be made worse by the shrinkage that occurs when some cement systems dry. Drying shrinkage

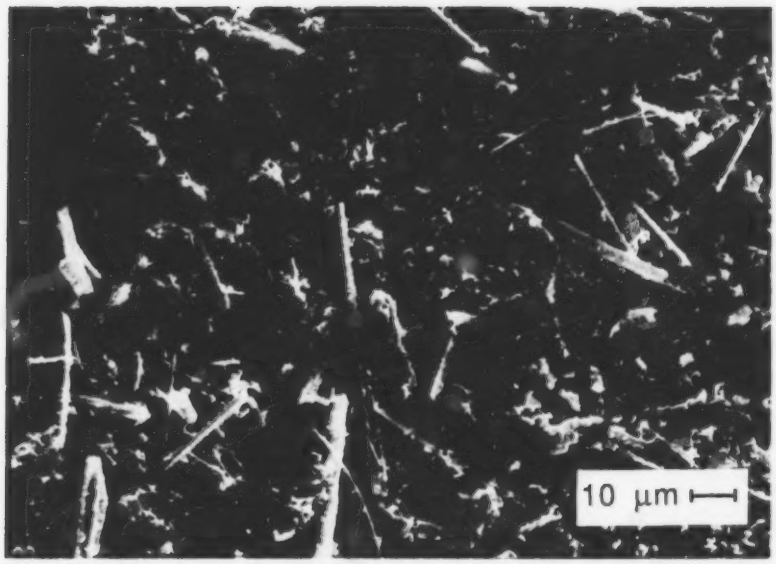

Figure 14-2. Scanning electron micrograph of filler-grade talc. Photo courtesy of MATEX Consultants Inc.

causes micro-cracking in the matrix and induces associated internal stresses that make tensile strength a very unreliable property. It is primarily to make up for these shortcomings that fibre reinforcement is used in brittle materials. For fibre reinforcement in these systems, the demand on the fibre to support stress up to failure of the matrix is small, and hence the increase in modulus is small. It is at, and after, failure that the fibre is required to perform, in particular by having the ability to support a rising load. This property is termed "pseudo-ductility," and it arises from progressive failure of the composite by multiple cracking and bridging of the crack by fibres. If there is sufficient volume of fibres of high enough strength, with good bonding to the matrix material, the composite will be held together after failure. The tensile strength, toughness and fracture behaviour of the composite primarily depend on the tensile strength and modulus of the fibre, its volume fraction in the composite, and such properties as fibre length and diameter. A number of fibres can meet these requirements, but cost and durability must also be considered; in these respects, asbestos has been an important component of a number of building products. Because asbestos has been such an important reinforcing agent in a broad range of product types, the problems raised by the move to replace it with substitute materials represent the major development in the field of fibre reinforcement. Many other developments relating to reinforcement of building materials have resulted from the search to solve the problems generated by the hazards associated with asbestos utilization.

Fibre-Reinforced Cement Products

Similarly, any discussion of the use of fibres to make cement composites must start with a consideration of asbestos-cement products and the problems generated by the need to remove asbestos from the building environment. Since its invention early in this century, asbestos-cement (AC), a combination of chrysotile asbestos fibre and normal Portland cement, has been a major source of factory-made building products. There are two major groups of AC products:

- flat or corrugated sheets, tiles, low pressure pipes and a variety of moulded conduits and gathering products for handling rain water in roofing systems;
- high-pressure AC pipes, designed for water pressures of ~2MPa.

A third class of product containing asbestos and cement is the now-defunct spray-applied fireproofing discussed later.

Asbestos-cement production has traditionally depended on the Hatschek process [6]. In this process, closely related to papermaking, a continuous sheet or pipe is formed, largely by controlled drainage of a cement-asbestos water slurry. The formation of the sheet or pipe depends greatly on the specific properties of asbestos fibres, which retain cement particles while permitting drainage of the excess water. After forming, the asbestos cement items are cured either by storage for 15–30 days, by acceleration with steam or by autoclaving for 24 hours. When autoclaving is used, the cement must be mixed with fine silica to produce the desired matrix components. North American AC production almost universally uses autoclaved curing.

Asbestos-cement production was the major consumer of chrysotile in North America, and remains so elsewhere in the world. The decline in North American consumption of AC products follows directly from the overall reduction of use of asbestos in consumer products. The inclusion of asbestos

fibres in normal concrete has been far less technically successful than in AC products. Mixing problems and the water demand of chrysotile fibres have generally lead to unsatisfactory products, and as noted earlier, other fibres have proven more valuable in concrete (see Chapter 10).

There are two factors driving the need to find fibres other than asbestos for use in cement-based products:

- the declining acceptance of asbestos in any building products, with the consequent declining market for AC materials;
- the desire to improve tensile and flexural strength, and toughness.

These have led to considerable research into fibre/cement composites in which both fibres and inorganic cements of various types have been considered.

Two types of building boards, internal partition boards and exterior cladding, are made using cement or other calcium silicate products as binders. For the most part, boards of this type compete with the concrete panel products discussed in Chapter 10. At one time, both interior and exterior products were made using asbestos fibres; now, most of these products are being produced in an asbestos-free form.

Cement board products are required to perform a number of functions, the most important of which fall into two groups: internal partition board, typically required to provide a fire-resistant or insulating lining for interior walls in both domestic and industrial buildings; and water-resistant cladding boards, originally used principally as roofing or exterior wall covering, with more recent use extended to interior applications as backing for ceramic tiles in tub and shower surrounds. These types of products provide substantial opportunities to the building materials producer as a consequence of two changes in recent years: the declining use of asbestos in buildings, and new building code regulations on tile-backing materials.

Traditionally, partition boards were made from AC compositions. The typical fire-resistant or insulating boards, developed in Europe during the 1950s, were based on amosite asbestos (an amphibole fibre) in an autoclaved calcium silicate or cement-silica matrix. Other partition boards were made from asbestos-cellulose-cement combinations incorporating high loadings of fibre (20–25%), 3–15% cellulose, and the remainder, chrysotile asbestos.

While all asbestos products are being discouraged in construction, those based on amphibole fibres are particularly suspect as health hazards. As a consequence, many of these products have been discontinued. Manufacturers have found considerable difficulty in developing replacements. Part of the difficulty has been in matching the performance properties of asbestos; a larger problem is related to production technology. As noted above, most traditional AC board products were made on conventional Hatschek equipment, and mix formulations and constituents were carefully chosen to meet the requirements of this process (which is not particularly flexible in terms of product reformulation). Thus, when faced with removing or replacing asbestos in their products, the manufacturers were also faced with a complete re-tooling of their process, in addition to the demands of meeting performance requirements with new materials.

Generally, two main approaches have been followed. Some producers have attempted to replace asbestos with other reinforcers in a traditional calcium silicate matrix; others have both replaced asbestos and introduced other matrix materials. A third approach has been to use other production methods such as casting or continuous manufacturing on a wallboard-type system.

Alternative fibres and reinforcements to asbestos were discussed earlier in this chapter in relation to the broad need for replacements in a range of building products. In terms of asbestos-cement boards, alternative fibres that can offer some (but not all) of the properties of asbestos include cellulose, E-glass, carbon and Kevlar. Cellulose, unless treated with fire retardents, does not give adequate fire resistance in the products. As discussed earlier, glass has not proven completely satisfactory in cement matrices due to alkali-induced deterioration. In addition, for low-cost items such as interior boards, carbon and Kevlar fibres may be too expensive, their use being restricted to high-performance components. Overall, cellulose appears to be the fibre of choice in Europe, Australia and Japan [6]. Fire retardents are added along with incombustible mineral components such as mica, vermiculite, glass fibre or mineral wool. Development of boards of this type has offered opportunities to mica and vermiculite producers. According to Benbow [19] the demise of asbestos in fibreboard products has given a considerable impetus to markets for dry-ground mica. In this application, the low shrinkage and high stability of mica under fire exposure are its main virtues; however, a mica low in MgO is required for the best performance.

On a basis of cost, fire resistance and performance, glass or mineral wool fibres are the best alternative to asbestos for board products. The problem with their use is in the loss of strength experienced when glass fibres are incorporated in a cement matrix (see above). Unless expensive AR-glass is used, or coatings are applied, the resulting products show poor durability in service. To overcome this problem, inorganic binders which are less aggressive than cement or calcium silicates can be employed — for example, cements based on, or incorporating, gypsum, calcium sulphoaluminate, slag, silica fume, fly ash. Many of the non-Portland cements discussed in Chapter 9 are suitable for use with glass or mineral wool fibres.

Whereas the North American products appear to be based on relatively simple cement-aggregate-fibre mesh compositions, a trend among European products has been towards using other mineral constituents in cement boards to

simulate previously popular asbestos-cement products. One example is a product called Minerit™ made by the Partek Corporation in Finland. The board is manufactured by the Hatschek process. It is described as consisting of cement, cellulose fibres and "different mineral fillers." Visually, some grades of the board appear to contain either mica or vermiculite. Similar products under the trade name Vartii™ are produced as corrugated roofing materials which are described as "tiles" by the manufacturer, but of substantially larger dimensions than normal roofing tiles.

The opportunities to apply a variety of industrial minerals in thin panels/boards appear excellent. In addition to the rapid growth of the market, which will increase the volume of cement used in these products, other mineral-based materials are required, such as natural lightweight aggregates, synthetic lightweight aggregates, fibrous substitutes for asbestos, mineral and glass fibres, phyllosilicates, and vermiculite. This potential market is recommended as worthy of further investigation. It has great potential to provide specific opportunities to a relatively broad range of mineral products.

Cementitious Fireproofing

The fire endurance rating of concrete and steel floors and roofs is often governed by criteria governing the temperature rise of the surface rather than by structural considerations. A traditional method to increase the fire rating of building structures and materials has been through the use of cementitious fire protection coatings which can be spray-applied directly to the substrate: for example, steel joists or decking, metal lath, suspended ceilings, reinforced concrete, precast concrete units, and even interior foam plastics on wall and ceiling insulations. Materials of this type, in the strict sense, are regarded as non-load bearing although they are generally self supporting.

In view of asbestos's superior fire-resistant properties and long fibre length, the fireproofing and insulation area was once dominated by the now defunct spray-applied asbestos-cement products. Several different types and combinations of material have now been used successfully to replace asbestos, although the most widely used and proven materials are mineral wools and vermiculite in various combinations with Portland cement. Glass wools, perlite, mica, ceramic fibres and other binders are also found in some formulations.

The products can be spray-applied to the substrate in various densities to achieve different predetermined fire ratings, the main requirement being that they are pumpable and adhere properly to the surface. As with other pumped cement mixes, chemical flow aids and other additives are included in the mix. Recent development in this area has been towards grades with sufficient durability for exterior applications, particularly in terms of freeze-thaw resistance. Tradenames for mineral fibre-based products in North America include Hibar, Cafco, Spraydon and A/D Type F.P.; vermiculite-based products are sold under the names Monokote and Zonolite.

Among mineral types, vermiculite and perlite are good insulants, and when expanded, also make good loose fill insulation for cavity walls apart from their use in cement-based coatings. It has been estimated that some 70% of the market for these minerals lies in the construction industry in the form of lightweight thermal insulating and temperature resistant aggregates in cement [6]. As an example, high temperature block insulations based on exfoliated vermiculite bonded with potassium silicate are produced by Skarrehage Molerwaerk A/S in Denmark [6].

PROSPECTS FOR INDUSTRIAL MINERALS

Overall, the need to find suitable materials to substitute for asbestos in composite building products offers some good opportunities to the industrial minerals industry. Some minerals have become established for this purpose and some materials have been developed. However, there is an urgent need for more research and development in this area, including both the examination of natural minerals and the synthetic production of new substitutes from minerals. In particular, there are good opportunities for the industrial minerals industry to examine undeveloped resources of suitable minerals, especially for the production of alkali-resistant fibres for use in cemented systems, and mineral alternatives for asbestos, among which the following appear worthy of further investigation:

- zirconia for alkali-resistant glass
- vermiculite
- wollastonite
- clay minerals

In terms of alternative products, the non-Portland cements discussed in Chapter 9 hold considerable potential as a means to solve the problems associated with glass fibre-alkali instability. Specifically, in relation to board products, Ontario sources of mica, vermiculite and wollastonite appear able to benefit from the growth in this market.

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15. New Materials

- Lime
- Silica
- Kaolinite, illite,
- Montmorillonite
- Vermiculite
- Pumice
- Clay
- (Xonotlite)
- (Portland cement)
- (High alumina cement)
- (Calcium sulphate)
- (Mica)
- (Alumina)

Since about 1975, research and development efforts, some of which has been in fields not directly related to building products, have produced a number of new materials that appear to have significant potential in various construction applications. Production of these materials all involves substantial chemical or physical processing of industrial minerals. "New inorganic materials (NIMs)," a term coined by ICI in Britain, was originally applied to a group of materials, based on hydraulic cements that had remarkable "uncement like" properties. The term might now be extended to include a number of other products, including plasticized vermiculite, chemically-activated clays (geopolymers) and a new Japanese xonotlite-SBR latex composite material. All are in relatively early stages of development but are considered to have substantial promise as new applications for industrial minerals in building products.

CONTROLLED POROSITY (MDF) CEMENTS

The relationship between strength and porosity in ceramics and cemented materials has been known for many years. Essentially, pores or macro-defects place a limitation on the strength potential in such systems that is difficult to overcome by traditional methods of mixing, placing and (in the case of ceramics) firing.

In the case of the cement systems that are of interest in the present context, elimination of macro-defects in the cast products gives significantly improved strength and toughness. For this reason, they have been termed macro-defect free (MDF) cements, but they are also known variously as "new inorganic materials (NIMs)" and "chemically bonded ceramics (or cements) (CBCs)." Described in a series of publications and patents, research by ICI Runcorn, U.K., has produced a range of innovative materials with the following properties [1-3]:

- Compared to hydraulic cements, MDF cements have improved tensile, flexural and compressive strengths, fracture energy and stiffness. They are faster setting and hardening, have higher surface hardness, and are less sensitive to water.
- Compared to metals, MDF cements have strength approaching that of aluminum (but much lower than steel) and resistance to corrosion.
- Compared to plastics, MDF cements have greatly increased stiffness and a fracture energy similar to acrylic plastics and polystyrene. Unlike plastics, they are non-combustible and have high surface hardness.

Typical physical and electrical properties of MDF cements are collected in Table 15-1 with comparison to other materials in Table 15-2.

The developers of MDF cements see potential applications where use is made of the improved stiffness and strength of the materials, coupled with non-combustibility and good workability. Unlike other cement materials, the materials possess sufficient mechanical performance to enable them to be worked by common techniques such as machining, drilling, sawing and pop-rivetting. They can also be coloured by pigmentation or painting and produced with a variety of surface textures and patterns.

MDF cemented items can be joined together or to other materials with common adhesives, such as epoxies, and can be laminated to organic foams, wood, gypsum, and other cement products to provide hard, decorative and protective surfaces.

To use MDF cements, the components, hydraulic cement (typically high alumina cement but also Portland cement), rheology-aid, water and other additives, are mixed to a mouldable dough with a putty-like consistency. Subsequently, the dough can be shaped by most of the standard techniques available in the plastics, cement and ceramics industries, such as compression moulding, stamping, extrusion, rolling and calendering. Mould times can range upwards from less than one minute depending on composition and product size. Mould temperatures range from ambient to about 140°C.

Typical end-forms which have been made include rods, sheets, shaped sections, such as corrugations and profiles, together with surfaces for other materials, such as wood,

TABLE 15-1 TYPICAL PROPERTIES OF MDF CEMENT

Physical Properties	
Flexural Strength	40–150 MPa
Flexural modulus	25–40 GPa
Fracture energy	50–1000 Jm^{-2}
Direct tensile	30–100 MPa
Density	2.3–2.5 $g.cm^{-3}$
Coefficient of linear expansion	~10 x 10^{-6}/°C
Compressive strength	150–250 MPa
Thermal conductivity	~1 $Wm^{-1}K^{-1}$
Electrical Properties	
Resistivity	up to $10^{12}\Omega$ cm
Breakdown potential	20–40 KV per 3 mm
Tracking resistance	high

Source: ref. [1]

TABLE 15-2 COMPARISON OF PROPERTIES OF MDF CEMENT WITH OTHER MATERIALS

Material	**Density** ($g.cm^{-3}$)	**Flexural Strength** (MPa)	**Young's Modulus** (GPa)	**Fracture Energy** (Jm^{-2})
MDF Cement	2.3–2.5	40–150	25–40	50–1,000
Portland cement paste	2.3	5–10	20	20
Asbestos-cement	1.4–2.2	20–60	25	300
Glass	2.5	70	70	10
Aluminum and its alloys	2.7	150–400	70	10,000
Steel	7.9	500–1,000	200	10,000
Polystyrene	1.1	70–120	3	1,000
Polymethyl-methacrylate	1.0	70–120	3	1,000
SMC/DMC	2.0	200–300	15	10,000

Source: ref. [1]

gypsum and foams. The mouldable dough can be a useful material in its own rights. For example, as a flexible rod or ribbon, it can be used in other processes before it has set to provide seals and insulators for components. Setting to a rigid form can then take place at ambient or low temperatures.

Though the materials are typically porous, their properties result from the deliberate manipulation of the pore-size distribution to eliminate large voids — hence the concept of "macro-defect free" systems. The close packing of cement particles, through which macro-defects are eliminated, at low water content, has been obtained by the use of polar polymers that affect deflocculation of the paste. The essential feature in obtaining these dense, finely pored materials lies in deflocculation of the cement/water paste.

At the present time, the potential applications for MDF cements in building materials appear to be for relatively small-sized factory-manufactured units — for example, window frames, lintels, door frames, joists and other easily extruded forms. Typically these have been produced in wood or plastic. The advantages of using MDF cements would be in the precision to which they could be made, their strength and fire resistance.

The MDF cements exhibit a much higher breaking strain than conventional cements and a vastly different stress-strain relationship in which there is a small but significant region of plastic deformation (Fig. 15-1). This plastic behaviour has even allowed workers at ICI to produce a cement spring with a maximum elastic strain which is an order of magnitude higher than is possible with ordinary cements [2].

ICI has also done considerable work on other polymer-modified cements in which the particle size of the cement is strictly controlled to the point where bi- and tri-modal distributions of cement particles are used [3]. The preparation methods are similar to those used for the calcium aluminate MDF cement. Mineral additives such as silica powder and alkali-stabilized silica were found to improve flexural strength. Similar results have been reported with gypsum-polymer composites (see Chapter 8).

In a different approach to the problem of porosity reduction in cement, deflocculation of the paste component has also been achieved by using a combination of superplasticizers and silica fume (see Chapters 9 and 10). In this way, materials termed "densified systems containing homogeneously arranged, ultra-fine particles (DSP)," can be produced with compressive strengths of 130–250 MPa. DSPs have been developed by the Danish cement company Aktieselskabet Aalborg Portland-Cement-Fabrik under the trade name DENSIT™. They were extensively described by Bache in a paper presented in Ottawa in 1981 [4,5].

In contrast to the MDF cements where the fabrication methods that must be used are not compatible with the introduction of coarse aggregates, DSP systems have been made into concrete products. These have been used successfully in a number of practical applications including a

TABLE 15-3 POTENTIAL END USES FOR MDF CEMENTS

Industry	Application	Current Materials
Building	Floor, wall, roof tiles	Ceramics, wood, concrete asbestos/cement
	Cladding and siding, corrugated sheets, fences	Aluminum, asbestos/cement, metal, wood
Pipes	Pressure, sewer and drainage	Asbestos/cement, plastics, lined-metal
Electrical	Insulators, sockets, switchgear, fittings	Porcelain, glass, plastics
Appliance	Acoustic panels, cabinets	Wood, glass, reinforced plastic
Materials	Laminates with foam & wood Containers, packaging Manholes, drains, covers Prefabricated structures	Gypsum/urethane Plastics, metals Cast iron, concrete Various

Source: ref. [1]

protective overlay for concrete floors subject to contact with aggressive agents, as a medium to line pipes, to form screws, car body components, wheels, and paddles (as alternatives to cast bronze and steel). They have also been found to perform much better than conventional metal parts under abrasive conditions in a cement plant. Since concrete materials of this type may be some two to three times stronger than even high strength concrete (70–80 MPa), they place a considerable demand on the strength of the aggregates such that a material such as sintered bauxite (alumina) must be specially manufactured [5].

A considerable amount of interest is now being shown in controlled porosity cements in North America. Similar materials, termed chemically bonded cements (CBCs), have been developed by Cemcon Corp., U.S., and licensed by Occidental Chemical Co., Lanham, Maryland [6-8]. CBCs are a described by Cemcon as "...an emerging class of highly cross linked cements which are made by adding cross-linking agents to a conventional cement base, then mixing in a small amount of water." This appears to describe the MDF materials produced by ICI. It is claimed that CBCs are easier to process than sintered high-temperature ceramics and, at 70,000 psi, nearly as strong (and approximately ten times stronger than conventional cements). Specific properties may be engineered into CBCs by reinforcing with metal, fibres or minerals: for example, Cemcon promotes metal-reinforced as a less expensive alternative to steel moulds for short production runs, and graphite particle-reinforced for brake linings [7,8]. Other potential applications include military armour (Kevlar reinforced), sound and heat insulation, circuit boards, and electronic component encapsulation.

In Canada, Relmech Manufacturing Ltd. of Elmira, Ontario, has recently announced the development of a new composite material for electronic and electrical applications which is reported to be based on the chemically bonded ceramic concept [9]. Related research has been conducted by Matex Consultants Inc. of Mississauga.

Other related classes of controlled porosity cement materials are under active research and development in many countries An example of a material which has been commercialized is the so-called 3L concrete (low density, low absorbent, lightweight aggregate) developed by Chalmers Technical University in Gothenburg, Sweden [10,11]. A key feature of this concrete is the incorporation of a stabilizing additive (containing CEMOS polymer microspheres from Bofors Nobel Kemi, Sweden) which prevents segregation and contributes to its low absorptivity. This material is marketed as X-Concrete™ by Gaard Betong AS of Norway who report that it contains expanded clay or pumice, expanded polystyrene, XAD proprietary stabilizer, cement, sand and water. It is promoted for many applications including load-bearing sandwich walls, insulated floor and roof elements, soundproof walls, stairs and chimneys [12].

POLYMERS FROM MINERAL SILICATES

Polymeric compounds with silicon as the principal element are not new — in one form they are the familiar "silicone" materials ranging in properties from oily fluids to rubber-like solids. These are generally made by polymeriza-

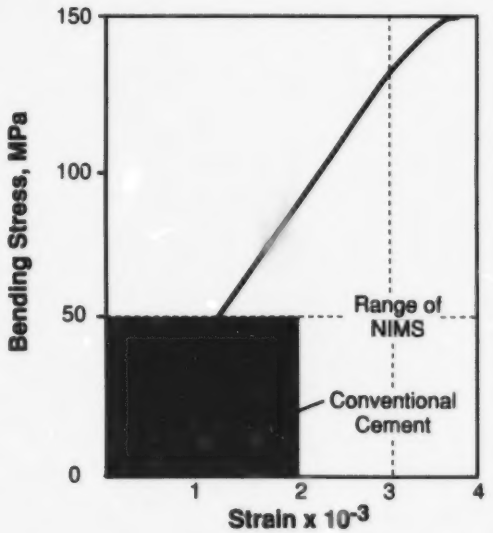


Figure 15-1 **Stress-strain relationship for MDF cement compared to conventional cement. Source: ref. (2)**

tion of organosilicon compounds (e.g. siloxanes and silanes) and are the basis of a major branch of the chemicals industry. An inorganic material bearing some resemblance to the silicones has now been produced directly from the mineral vermiculite. In 1983, Ballard and Rideal of ICI in Britain reported production of an inorganic layer material with mechanical properties similar to polyethylene but with the thermal stability of asbestos [13,14].

Vermiculite is a hydrous magnesium aluminosilicate which is one of a large group of phyllosilicate minerals that also includes montmorillonite and hydrobiotite. Among other properties in common, these minerals have layer structures that can be delaminated. Several methods have been proposed to delaminate vermiculite, the simplest being to heat the ore and vapourize the interlamellar water. This produces the familiar expanded product used as insulation in construction (see Chapter 14). Chemical ion exchange has been the preferred method to delaminate the mineral at the molecular level, this being the subject of several studies since the mid-1960s from which a number of patents have been issued [15].

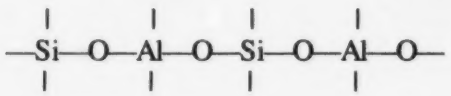
In a typical ion exchange process, the ore is soaked or refluxed in a saturated sodium chloride solution. In much of the early work, the vermiculite was then swollen by immersion in water. In the new ICI process [13,14], after thorough washing to remove the magnesium ions leached from the ore and the excess sodium chloride, the material is refluxed a second time in 2 molar *n*-butyl-ammonium chloride. The butyl-ammonium ion then replaces the sodium ions from the first exchange and also removes residual magnesium. The ore is again washed thoroughly to remove excess ions. During the second washing the ore begins to expand as water is imbibed into the interlammelar spaces and bulk volume increases of up to thirty times the original volume of the ore can take place.

The chemically swollen ore is then mechanically delaminated in a high-shear mixer or a colloid mill. Larger particles of the ore are removed from the delaminated component by sedimentation or sieving. The product at this stage is an aqueous suspension of highly dispersed lamellae. Simple evaporation of water from the suspension produces alignment of the particles to form coherent, almost transparent films.

Such films can be formed around fibres, particles or on metal surfaces, or they can become the walls of foams made by introducing air bubbles into the suspension. The potential range of products from this type of material has broad interest in glass coatings, insulation and waterproofing applications for construction materials. Clearly the technology is at an early stage of development but it should be of interest to producers of vermiculite and other phyllosilicate minerals. It is perhaps of most interest in Ontario because of the rather limited applications that have been available in the past for native vermiculite deposits [16]. Although vermiculite occurrences are known, their commercialization has been relatively unsuccessful due to poor delamination characteristics using the thermal methods [17]. Chemical methods may be more successful. Similarly, low-grade native mica sources may be usable.

GEOPOLYMERS

Geopolymers are a class of materials based on two- and three-dimensional inorganic aluminosilicate polymers:



and related structures, termed "poly-silalates."

One of the most interesting development prospects for the use of clay minerals is in the area of so-called "geopolymers," a class of materials based on chemically modified clay minerals. Much of the original study of these materials has been reported by Davidovits et al. [18-20] who, in 1982 and 1985, obtained patents covering the preparation of structural materials by applying heat and pressure to mixtures of alkali, clay and silica. Both natural and fired clays have been used, including kaolinite, illite and montmorillonite types [21]. Applications have been proposed in the production of materials for use in building, engineering, industrial and waste solidification fields. It is claimed that geopolymers are formed by the alkali activation of various minerals involving reactions of the product of calcination of kaolin or other minerals of similar structure with alkali compounds. A typical two part mix, termed Geopolymite 50™, comprises equal mass proportions of two components (A and B) with the following composition:

	Part A	Part B
SiO_2	20.95	30.22
Al_2O_3	- -	25.30
Fe_2O_3/TiO_2	- -	1.10
K_2O	25.98	0.63
CaO	- -	29.00
MgO	- -	2.76
F^-	- -	10.94
H_2O	53.03	- -

Setting times for these mixtures are said to be as short as 5 minutes to give geopolymer cements with tensile strength twice that of Portland cement. Curing is also possible under elevated pressure and temperature conditions. Geopolymers based on potassium as the alkali are said to be freeze-thaw stable. It has been suggested that geopolymers can be

included in blended cements to give high early strength, low shrinkage, and freeze-thaw, sulphate and corrosion resistance.

While not giving details of composition, Malone has noted that Lone Star Industries, a major U.S. cement supplier, has been involved in the development of a product called Pyrament™ blended cement. The products available are said to be based on the patents for geopolymers [21]. It is clear that these materials, while still at an early stage of development, offer great potential for the production of cements of controlled properties that would have applications ranging from repair of structures to the production of manufactured building sections. The production of these materials requires considerable addition of value to the clay minerals used and in some cases could be conducted on a relatively small scale close to the mineral sources. It is recommended that the industrial minerals industry consider these materials in more detail as potential uses for large quantities of mineral raw materials.

The potential use of clay minerals as supplementary cementing materials and as a source of alumina in the production of expansive cements is discussed in Chapter 9.

INORGANIC ARTIFICIAL WOOD

Another interesting development from Onoda Cement in Japan has been the announcement of an inorganic artificial wood material based on the mineral xonotlite, SBR latex, glass fibre and other proprietary additives [22,23].

Xonotlite is a natural calcium silicate hydrate mineral ($5CaO{\cdot}5SiO_2{\cdot}H_2O$). It can also be produced synthetically by hydrothermal treatment of a 1:1 lime-silica mixture at 150 - 400°C [24]. It is a fibrous mineral closely related to the tobermorite-type C–S–H gel found in Portland cement concrete and may be present in some autoclaved lime-silica products (see Chapter 7).

Although manufacturing details are not available, it appears that the artificial wood is made in two stages involving the initial formation of xonotlite by autoclave reaction of lime and silica at 210°C, followed by compounding the synthetic xonotlite with styrene-butadiene rubber (SBR) (0–20% by weight), glass fibre (0–10% by weight), and a cationic surface active agent to promote wetting of the solids by the SBR. The initially produced xonotlite appears to be in the form of fibres with a reasonably high aspect ratio.

The material is reported to have excellent mechanical properties (Table 15-4) including high fracture toughness and bending strengths and good machinability and non-flammable. It has now been commercialized by Onoda Cement, jointly with Naigai Mokuzai Kogyo Company, Tokyo, Japan, under the tradename ACE-LITE™ and is being marketed as a wood board replacement. The material has a bulk density of 0.5–0.55 $g.cm^{-3}$ similar to lumber, although densities as low as 0.4 $g.cm^{-3}$ are also produced. From the description available, it appears that ACE-LITE™ is best considered as a polymer composite material, rather than as a body formed by cementitious reactions. In this case, the binding element is the SBR latex, while the xonotlite serves the function of micro-reinforcement and filler. Basic reinforcement is provided by the glass fibre. It provides a good example of how the chemical processing of common industrial minerals such as lime and silica can be utilized in a high value-added product.

PROSPECTS FOR INDUSTRIAL MINERALS

For the most part, the new inorganic materials described in this chapter are still in the early stages of development and commercialization. In various ways, however, they provide some interesting opportunities for the development of industrial minerals, some of which might include:

- specialized binders and mineral additives for MDF cements; there may be opportunities for the production of specialized microfillers;

TABLE 15-4 PROPERTIES OF ACE-LITE ARTIFICIAL WOOD BOARDS

Bulk density	0.5–0.55 $g.cm^{-3}$
Bending strength	80–100 $kgf.cm^{-2}$
Bending elastic modulus	20,000–25,000 $kgf.cm^{-2}$
Compressive strength	80–100 $kgf.cm^{-2}$
Heat conductivity	0.085±0,0001 θ
Water absorption	150±5%
Expansion and contractiondue to water absorption	±0%
Nail pulling resistance	30–35 kgf/nail
Screw holding strength	20–30 kgf/screw

Source: ref. [23]

- vermiculite and possibly other layer minerals for chemical processing to inorganic polymers; there would appear to be good potential for the utilization of the poor quality sources of vermiculite in the province;
- kaolinitic clays for geopolymers; there may be potential for the utilization of the sand-laden clays of Northern Ontario; pending findings of research, it may be possible to extend the technology more generally to the clays in the south of the province;
- lime and silica for production of fibrous xonotlite.

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Part III
16. Conclusions

The principal focus of this report has been on the technical issues related to opportunities for the industrial minerals industry to increase the use of its products in building materials. However, the technical information will only have value in assisting the industry to achieve this objective if consideration is also given to the market environment in which building materials are produced, sold and used. Hence, the conclusions drawn from this study concern issues both of a market and a technical nature.

Construction is the major consumer of industrial minerals in Canada, and the extent to which the industrial minerals industry can benefit further from developments in building products will depend on a number of interrelated factors — for example, changes in the consumption of minerals in established products; the level of added value that can be introduced by processing minerals; the development of new materials and applications; and the competition presented by building products and materials that are not made from industrial minerals.

Building materials represent a diverse group of products, ranging from low value-added, unprocessed minerals, to high value-added manufactured building sub-systems such as prefabricated walls or floors and even complete buildings. As noted throughout Parts I and II of this report, while industrial minerals are the major raw materials for most building products, materials produced from wood, metals and petrochemicals present strong competition in many applications. As a consequence, some sectors of the industrial minerals industry are faced with developing strategies to cope with trends and changes in construction that reflect what we have chosen to term "the market environment " into which they sell their products. The conclusions that the study has reached from the perspective of the market environment, and its associated opportunities and threats are now summarized.

THE MARKET ENVIRONMENT FOR BUILDING MATERIALS

In Part I, it was shown how the industrial minerals used for construction reach the market. They may be supplied directly to the users, sent from the source to a processing operation, or they may pass through a number of processing stages. The sale of the mineral products may be made by the company that recovers the material, or it may be through various intermediate processors and suppliers; some or all of these organizations may be divisions of the same company. At the purchasing end, the builder, contractor or designer may decide which materials are used in a building, with varying levels of input from the building owner. Thus, the market environment for building materials is, for the most part, one in which the producer of industrial minerals is remote from the end use, and the ultimate consumer, i.e. the owner of the building, may be remote from the selection of materials.

Within this process, three substantial industrial sectors are involved: the mining and mineral processing sector, within which the recovery and primary processing of industrial minerals is conducted; the construction industry, responsible for the construction of buildings; and the building materials and products industry, which is, in the main, part of the manufacturing industry. We have examined in some detail the characteristics of the segments of these three industries and have concluded that the clients for building products are the people who decide which materials will be used in buildings. This group differs for different building types. For major capital projects, such as office towers or public buildings, materials selection is the responsibility of a design team, in consultation with the owner. In the low-rise commercial market, function and price determine the selection of materials and innovative approaches are unlikely, except to increase the speed of construction. In the single-family housing market, the owner has little input to materials selection and little attention is paid to productivity, materials being chosen on a price and tradition basis. Meeting the market demands of these various groups of people is one requirement placed on the construction industry. Other influential factors in the selection of materials relate more to the internal problems of the industry itself, the most important of which, in the context of materials and building technology, is the highly labour-intensive nature and low productivity of the building process.

We have concluded, that the technological and materials needs of construction can be expected to change in response to three trends in building construction:

- efforts by the industry to increase productivity by industrializing the construction processes;
- a move from new construction towards repair and renovation of existing structures;
- a response by builders to demands for more consideration of health, safety, lifestyle, durability and quality in buildings.

It is a principal thesis of this report that these changes in the market environment will stimulate new demands on the materials used in construction.

Productivity and Industrialization

There is considerable concern among industry commentators that productivity in construction, especially in the housing sector, is unacceptably low. Further, a number of crafts — for example, bricklayers — are experiencing a decline in recruitment of new practitioners. Together, these factors threaten to increase the cost of the labour component in some parts of the construction industry that use products made from industrial minerals. We consider it probable that these pressures will lead the builders to make changes in the methods and materials of construction. In general, we conclude that the industry will improve productivity largely by increasing the level of mechanization, automation, and prefabrication of building components that it employs — that is, by a process of *industrialization*. For some aspects of construction, industrialization is already quite advanced in Ontario, particularly in the factory production of building components. Factory-made components are extensively used in high-rise towers, and commercial and industrial buildings. In these projects, the use of innovative technology is possible when combined with building techniques that minimize the construction time and labour content. The process has had little influence in low-rise housing construction, beyond the use of factory-assembled roof trusses, wallboard, and window structures.

Repair and Renovation

A number of industry observers predict a growth in demand for repair and renovation of existing structures. We expect a considerable part of this growth to come from the need to repair and replace civil infrastructure. Though this is beyond the scope of this study, we strongly recommend that the industrial minerals industry consider this as an area for substantial market growth. Repair and upgrading of structures, renovation of older housing stock, and urban renewal are seen as continuing and expanding markets for products based on industrial minerals. Industrial minerals will be required to provide materials for upgrading structures and for special purposes in the repair of heritage buildings.

Improved Building Performance

There are indications that the owners and users of buildings are becoming more demanding of quality in structures. In particular, in offices and public buildings, owners and building managers are increasingly requesting that attention is paid to factors that influence the health, safety and comfort of occupants. It has been recognized that the efficiency of office workers and others is strongly influenced by the quality of the interior environment. In extreme cases, the "sick-building syndrome" may be experienced. Designers and builders are responding by giving more consideration to the role of building materials in affecting health, safety and comfort. Similarly, in housing the more sophisticated buyers are demanding attention to life-cycle costs and energy efficiency. In both of these areas, governments and regulatory authorities have recognized a need to protect consumer interests and have developed codes and regulations accordingly. These have already influenced the choice of materials for buildings and will continue to do so. In this context, particular attention has been given in Chapter 14 of the report to the issues raised by the need to replace asbestos as a construction material, and the opportunities that arise in this context for other industrial minerals.

We conclude that there will be a growing need to supply materials that are consistent with good indoor-air quality, occupant safety (e.g. non-flammability), energy efficiency, durability, and convenience of maintenance. These qualities are provided by materials made from industrial minerals.

Many of the plastic and polymer-based products competing with industrial minerals may experience more difficulty in meeting some of these requirements.

THREATS

The principal threats to industrial minerals in building materials come from potential substitute products that are either cheaper, more durable, more fashionable or more readily adapted to the changing needs of the construction industry. Such substitute products may be made from industrial minerals also, or they may be made from competing materials (Table 16-1). Industrial minerals have competed with other building materials such as wood and metals throughout the history of construction. In general, except for a recent increase in the use of metal and plastic products in cladding materials, changes that have occurred have tended to favour industrial mineral-based products. For example, the use of concrete to replace steel in structural components and to replace wood in floors and stairways. However , the use of plastics and other polymer-based products is a new threat to all traditional building materials. Over the past 10 to 20 years a growing number of polymer-based products has entered the construction marketplace. The processing of plastics is the fastest growing industry in Canada, with a growth rate averaging more than 2.2 times real GDP for the past 20 years. Approximately 26% of the output of the plastics industry in 1986 went into construction applications with this proportion expected to reach 29% by 1996.

One competitive threat that has become evident in conducting this study is the manner in which a number of products traditionally made from one industrial mineral are being replaced by products from another mineral. The two areas most affected by this are clay products and asbestos-based materials. Among clay products, sewer pipe has been displaced by cement-based or plastic alternatives, and brick and roofing tiles are also under considerable competitive stress. To a lesser extent, plastics and polymer-based materials threaten all cladding materials, inorganic insulation, while glass now sees some competition from transparent plastic sheeting.

If the producers of building materials can make changes to their products to make them more compatible with the changing needs of building practice many will remain acceptable in the market on the basis of their traditional nature.

TABLE 16-1 COMPETITIVE THREATS TO MINERAL-BASED BUILDING PRODUCTS

Product	Competing Materials	
	Mineral Based	Non-Mineral Based
Aggregates	None	Industrial wastes
Dimension stone (natural)	Synthetic stone, concrete masonry or cladding, glass	Polymer-based cladding
Lime	Portland cement	
Gypsum	Portland cement	FGD gypsum Polymer-based cladding
Portland cement	Other inorganic cements	Supplementary cements (fly ash, slag, silica fume) Polymers
Concrete	None	Polymer concrete Plastic cladding
Clay	Concrete	Plastics
Glass	None (vision) Concrete, stone (cladding)	Aluminum, steel, vinyl (cladding) transparent plastics (vision)
Asbestos	Wollastonite, glass, vermiculite, mica, glass fibre	Organic and synthetic fibres

TABLE 16-2 SUMMARY OF POTENTIAL MARKETS FOR INDUSTRIAL MINERALS IN BUILDING MATERIALS AND PRODUCTS

Product	Dimension stone	Aggregates	Lime products	Gypsum products	Portland cements	Misc. cements	Concrete products	Clay products	Glass	Filled polymers	Asbestos subst.	New materials
Principal Structural Materials												
Stone	✓	✓					✓					
Gravel		✓					✓					
Sand (Fine aggregate)		✓	✓		✓	✓	✓	✓				
Limestone (Calcite & Dolomite)	✓	✓	✓		✓	✓	✓		✓	✓		✓
Gypsum				✓	✓	✓				✓		
Clays and Shales (Heavy)		✓			✓	✓		✓			✓	✓
Other Minerals												
Silica (Quartz)			✓			✓			✓	✓		✓
Vermiculite				✓			✓			✓	✓	✓
Perlite				✓			✓			✓	✓	
Wollastonite				✓			✓	✓		✓	✓	
Mica				✓			✓			✓	✓	✓
Asbestos							✓			✓	✓	
Diatomite										✓		
Pumicite				✓						✓		✓
Serpentine	✓						✓			✓		
Barite										✓		
Nepheline Syenite								✓	✓	✓		
Magnesite						✓						
Fluorite						✓						
Soda Ash									✓			
Talc, Soapstone	✓							✓		✓	✓	
Kaolin						✓		✓	✓	✓		✓
Bentonite										✓		
Attapulgite										✓	✓	

BARRIERS

Barriers exist to both the development of new building products and their acceptance by the construction industry. Inadequate levels of research and development and reliance on imported technology and materials are contributing to the slow development of new materials that could improve productivity in construction. When materials are available they are not always readily accepted. While the larger construction companies and building materials producers are generally aware of the major developments in new materials and technology occurring abroad, effective technology transfer to the smaller, independent companies is less efficient. In some cases the technology is being adopted; in others it may be seen as not appropriate; and in other instances it may be considered too advanced. The building products manufacturers are aware of new materials and appear willing to introduce them, if the market (i.e. the construction industry) will accept them. A number of factors hinder the introduction of new technology into the construction process as follows:

- concerns over liability lead the construction industry to be extremely conservative in specifying new materials or innovative practices;
- market tradition and a conservative view of structural design has held back some innovation;
- the almost insignificant level of R&D conducted by the construction industry has meant that most of the industry has no investment in, or understanding of, the product of research effort;
- union regulations, trade demarcations, and codes may restrict the use of innovative practices, new materials, or increases in productivity and negate any advantages that they bring;
- other barriers result from fragmentation of the industry, a relatively low level of technical education among some practitioners, especially in the housing construction field, and lack of perceived short-term returns for some developments.

At the same time, there are clear indications that some parts of the industrial minerals industry are not fully aware of off-shore technical developments that present new market opportunities for their products in construction. For the most part, we find that technology transfer to, and between, the minerals producers, the construction industry and the building products manufacturers falls into a grey area between various government and industry jurisdictions and would benefit from coordination.

OPPORTUNITIES

In a competitive market, changes, such as those that we anticipate will continue to affect construction, bring both opportunities and threats to new and established suppliers of materials. We have concluded that the challenge to the industrial minerals industry is to respond to these opportunities and develop strategies to defend its position in the face of the threats. If the industry, or sectors of it, fail to respond to these changes, we conclude that other industrial groups — notably the metals and plastics manufacturing industries — will increase their penetration into what have traditionally been safe markets for industrial minerals. These industries, with their strong base in manufacturing, marketing and R & D, are well

TABLE 16-3 OPPORTUNITIES AND AREAS OF GROWTH FOR INDUSTRIAL MINERALS — ESTABLISHED BUILDING PRODUCTS

Minerals	Opportunities
Stone	Dimension stone, cladding and flooring Aggregates
Gypsum	Gypsum wall board Portland cement
Limestone	Portland cement Aggregate
Shales and clays	Brick, tile, Portland cement
Silica	Glass, insulation
Vermiculite	Insulation and fire-proofing
Filler minerals	Sealants, caulks, plastic products

positioned to bring new developments from high-technology materials applications into the technologically less-sophisticated building sector.

The opportunities and threats facing industrial minerals are expected to be of concern both to producers of long-established products and to those expecting to respond to new demands in building materials. Most building products are made from the same raw materials that have served construction for centuries. Included among these are a core group of industrial minerals that, over time, have become regarded as the main sources of structural materials (Table 16-2). In some sectors, these are gradually being supplemented by other minerals used in a variety of minor roles.

Among the principal structural minerals, no major changes are anticipated in the ways in which they are used in established building products, many of which represent areas of potential growth (Table 16-3).

An important opportunity for the industrial minerals industry clearly remains in continuing to supply a major portion of the materials used in construction. Meeting the current needs of construction has generally served the building materials industry well in an expanding market, and will likely continue to do so. However, two factors must be considered: first, the market for construction in some sectors, especially single family housing, is no longer expanding in Ontario; and second, new materials not based on industrial minerals are entering the market place. If the Ontario industrial minerals industry is to increase the value of its shipments for existing construction applications, it will need to consider:

- increasing market size by increasing exports
- increasing its market share by replacing competing products
- defending its existing market share against competing materials

TABLE 16-4 OPPORTUNITIES FOR ONTARIO MINERALS AND PROCESSING — IMPORT REPLACEMENT

Imported product	Mineral/Process Requirement
Thin cut dimension stone	Stone/cutting technology
Ceramic tiles	Kaolin and other fine clays / roller kiln technology
Non-Portland cements	Clays, high alumina minerals, fluorite, magnesite, dolomite, gypsum
Fillers and special-purpose minerals	Gypsum, kaolin, wollastonite, vermiculite, mica, alumina hydrate

TABLE 16-5 OPPORTUNITIES TO INCREASE ADDED VALUE IN SOME MINERAL-BASED PRODUCTS — ESTABLISHED APPLICATIONS

Mineral	Product Opportunities
Stone	Thin-cut, polished stone facings for composite panels
Lime	Lime-silica masonry
Gypsum	Gypsum-bound composites Gypsum fillers and fibres
Cement	Precast concrete components Wall, floor and ceiling systems
Clay	Masonry panels Low-density aggregates Clay-based fire barriers and waterproof sheeting
Fillers and misc. minerals	Chemically modified minerals Asbestos substitutes

In general, building materials, unless they have been extensively processed, are of insufficient value to be transported great distances. As a result, exports are usually to the northern United States or to other provinces in Canada, and frequently comprise: shipments to meet local shortages of production capacity, such as with cement and fired-clay products; the transfer of products between companies belonging to the same integrated producing group, such as glass and wallboard; or unprocessed raw materials, such as gypsum rock. In this form, exports of building materials to supply existing needs are dependent on the level of building activity in the U.S. The existing market for industrial mineral-based building materials produced in Ontario should thus be considered to include a substantial U.S. component. Unless the nature of the products offered changes, this export market will likely remain unchanged. However, if the Ontario industry develops products of added value, the similarity between construction technology elsewhere in Canada and in the U.S. and practices in Ontario, should make their acceptance easier, and new markets could be established.

Increasing market share requires competing with imported products and other materials. Because most of the major raw materials required to produce conventional building products are widely available, competition will be more effective if the products shipped by Ontario producers are processed to a substantial level of added value. Established product areas in which replacement of imported materials with those made from industrial minerals available in Ontario are shown in Table 16-4.

Thus, in both aspects of achieving incremental revenue from the province's industrial minerals, processing to add value is as a key component. In short, the industrial minerals producers can improve their market position by continuing to supply products to existing applications, while working to support those applications with more highly processed goods. Table 16-5 summarizes some areas where potential exists to add value to products used in building applications by the introduction of existing technology.

In some sectors, we have seen that substantial technological development may be required for industrial minerals to meet the opportunities arising from the changing needs and new applications in building construction. It is clear from consideration of the technical trends discussed in Part II that many manufacturers of building products have already recognized some of these changes and are starting to provide or develop complementary materials. Some of the product types that we have concluded will be required to meet these needs are shown in Table 16-6, with an indication of the minerals expected to benefit from their production. Some new potential applications for building materials that offer opportunities to industrial minerals are presented in Table 16-7.

In the area of repair and renovation, we expect the major opportunities for the industrial minerals producers to reside in producing established materials. Some new applications may arise in custom production of replacement building components to match existing structures made from stone or clay products. Repair of deteriorated parking structures may result in the use of polymer concrete products requiring special aggregates, and patching compounds based on non-Portland cements may be used in similar applications.

In relation to the issues of health and safety, there are opportunities for the use of industrial mineral products to replace some of the polymer-based materials currently suspected of contributing to poor air quality in buildings — for example,

TABLE 16-6 MINERAL-BASED PRODUCT TYPES COMPLEMENTARY TO FUTURE NEEDS OF BUILDING CONSTRUCTION

Product Type	Materials or Minerals Used
High strength aggregates	Trap-rock, basalt, synthetic alumina
Lightweight aggregates	Clay, shale, vermiculite
Non-Portland cements	Clays, high alumina minerals, fluorite, magnesite, dolomite, gypsum
Panels based on:	
Masonry	Stone, brick, block
Thin-cut stone	Dimension stone, lightweight aggregates
Lightweight concrete	Clay, shale, vermiculite
Polymer concrete	Aggregates, quartz
Glass	Silica, nepheline syenite
Fillers and reinforcers	Calcite, talc, silica, mica, kaolin
Asbestos substitutes	Wollastonite, vermiculite, mica, perlite, glass fibre

TABLE 16-7 OPPORTUNITIES FOR INDUSTRIAL MINERALS — NEW BUILDING PRODUCTS AND APPLICATIONS

Minerals	Opportunities	Time to Implement
Stone	Panels	Immediate
	Special aggregates	Immediate
Lime	Lime-silica masonry	Immediate
	Xonotlite composites	1 year
	Precast autoclaved lightweight concrete (PALC)	3 to 5 years
Calcium sulphate	Fillers and fibres for polymers	Immediate
	Wood-filled gypsum and gypsum board	Immediate
	Gypsum composites	3 to 5 years
	Cast-plaster products	Immediate
	Raw materials for sulphate-based cements	Immediate
Clays	Customized ceramic products for renovation	Immediate
	Kaolins for decorative tile	Immediate
	Clays for ceramic panels	Immediate
	Raw materials for high-Al cements	Immediate
	Lightweight aggregate for high-rise concrete	Immediate
	Fire barriers and waterproofing	1 year
	Geopolymers	3 to 5 years
Silica	Substitute for silica fume	3 to 5 years
	Raw material for synthetic wollastonite	3 to 5 years
	Precast autoclaved lightweight concrete	3 to 5 years
	Lime-silica masonry	Immediate
Vermiculite and other phyllosilicates	Silicate polymers	5+ years
	Substitute for asbestos	Immediate
Magnesite/dolomite	Raw materials for magnesia-based cements	Immediate
Fluorite	Raw material for regulated-set cements	Immediate
Wollastonite	Substitute for asbestos	Immediate
	Filler/fibre for polymers	Immediate
High-Al minerals	Raw materials for high-Al cements	Immediate
Filler minerals	Plastic composite building products	Immediate
Basalt, traprock, corundum	High strength aggregates	Immediate

UFFI (foamed insulation).

More emphasis may be placed on the non-toxic, non-flammable nature of most products made from industrial minerals in comparison with competing plastic products. A major opportunity also exists in the development of inorganic, non-toxic replacements for asbestos for use in a range of construction applications. Wollastonite, mica, and vermiculite, among others, have potential applications in this field.

As the issue of durability becomes more important, increased use will be seen of materials such as high-strength concrete, polymer concrete, cement-based masonry/board products, and finished dimension stone. Some composites based on polymers filled or reinforced with mineral products may also be used where exposure to aggressive environments is a factor in durability.

It is notable that many of the opportunities discussed above relate to building products that are factory-made — for example, panels, composites, cast and formed masonry, tile, finished stone and precast concrete. This reflects the level of industrialization now existing in the construction of high-rise office towers and low-rise industrial structures. Products developed to meet the requirements raised by industrialization of this sector are now a common feature of the output of the building materials industry. Although industrialization has not yet made much progress in house construction, we have concluded that this market has considerable potential for industrialization and the use of prefabricated components.

It is not our purpose in this report to suggest that the development of manufactured housing is a current trend in Ontario; this is definitely not the case. However, we do conclude that if growth can be stimulated in factory production of housing or housing components, a major opportunity for the use of industrial minerals could be created. This could present a substantial opportunity to producers of building materials made from industrial minerals, though it will be also an area of extensive competition from other materials.